State of Utah
DEPARTMENT OF NATURAL RESOURCES
*Division of Wildlife Resources - Native Aquatic Species*

# THE WHITE RIVER AND ENDANGERED FISH RECOVERY:

# A HYDROLOGICAL, PHYSICAL AND BIOLOGICAL SYNOPSIS

**Publication Number 00-37**
**Utah Division of Wildlife Resources**
**1594 W. North Temple**
**Salt Lake City, Utah**
**John F. Kimball, Director**

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**Final Report**
**September 1998**

**Updated and Edited**
**September 2000**

**Prepared for:**
**Recovery Implementation Program**
**for Endangered Fish Species of the Upper Colorado River Basin**

**Project No. 21**

**Prepared by:**


**Leo D. Lentsch**
**Native Species Coordinator**

**Brian G. Hoskins**
**Wildlife Technician**

**Larissa M. Lubomudrov**
**Wildlife Technician**



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**John F. Kimball, Director**

Updated and Edited by:

Matthew E. Andersen
Native Aquatic Species Coordinator

and

Adrian Paschal
Research Assistant

Utah Division of Wildlife Resources
1594 West North Temple, Suite 2110
Salt Lake City, UT 84114-6301

September 2000

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## ACKNOWLEDGMENTS

We are grateful to Doug Osmundson, Keith Rose, Don Archer, Jack Schmidt, Bill Davis, Larry Crist, Gary Burton and the Program Director's Office for their review of the report.

This study was funded by the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. The Recovery Program is a joint effort of the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Western Area Power Administration, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, and the Colorado River Energy Distributors Association.

## FORWARD TO THE 2000 EDITION

This report was accepted as final with revisions by the Biology Committee of the RIP in February 1999. In March, 1999 revisions were received from Biology Committee members, requesting that the data be updated and the recommendations be revisited. Not all data in this report could be updated, as some was collected for a limited time, either as part of a specific agency effort or for a specific study. Where updated data or a more critical review of the data indicated different conclusions and recommendations, such changes were made. However, in light of the fact that this report has already been accepted by the Biology Committee as final, editing of content and conclusions was minimized. It is intended that the edits and updates included in the 2000 edition of the document address the concerns of all Biology Committee members.

Respectfully submitted,

Matthew E. Andersen

## EXECUTIVE SUMMARY

The largest Colorado pikeminnow population in the Upper Colorado River Basin (UCRB) resides in the Green River system. The White River, a tributary to the Green River, provides habitat or refuge for the extended Colorado pikeminnow population and contributes seasonal streamflow and sediment to the Green River system. Because of its physical and biological contribution to the Green River and its year-round use by adult Colorado pikeminnow, the White River plays an important role in the recovery and protection of Colorado pikeminnow.

In the White River basin, water demand has increased with human development. Water development projects impact White River hydrology and sediment transport which can, in turn, affect resident Colorado pikeminnow populations. The objectives for this study were: 1) to compile historical biological, hydrological and physical data for the White River, 2) to analyze physical, chemical and biological features of the White River important to endangered fishes and, 3) to identify parameters for long-term monitoring to insure these features are maintained. We examined physical, chemical and biological characteristics during three development periods in the UCRB: early (1895-1945), middle (1946-1984) and post Taylor Draw Dam (TDD) (1985-2000). The boundary between the early and middle development periods corresponds to historical increases in water demand. The boundary between the middle and post TDD periods corresponds to completion of TDD, the only dam on the White River.

Physical, chemical and biological data from previous studies on the White River and from U.S. Geologic Survey gage stations on the White, Green, Yampa and Duchesne rivers, were analyzed to detect changes between development periods. Physical variables examined include discharge, temperature and suspended sediments. Between the early and post TDD period, discharge decreased in the summer months (July to September) due to evaporative and agricultural depletions. Evaporation from TDD depleted streamflow by less than 1% (March through October). Depletions from water diversions ranged from 8% to 12% annually (Colorado Division of Water Resources 1992-94). Flood frequency analysis demonstrated that TDD does not significantly reduce flood frequency, but maximum, flooding streamflows were reduced over 40% at Watson, Utah following installation of TDD. Although average annual diversions exceed the average basin yields, much of the diverted water was returned to the system, so that consumption now totals about 5% of the average basin yield. Baseflows were relatively stable throughout the three development periods at Meeker, Colorado. At Watson, Utah, below TDD, winter baseflows are higher than historic levels, and early spring floods have been reduced. Hypolimnetic draws from TDD lowered downstream water temperatures in the summer by 2-3°C (Chart 1987). During winter, hypolimnetic draws elevated downstream water temperatures which often results in ice free conditions for 15 kilometers below TDD (Chart 1987). Taylor Draw Dam also traps sediment, thereby reducing sediment loads and turbidity downstream (retention rates of 30% to 98%, depending on stream inflow) (Tobin and Hollowed 1990).

Chemical variables examined include specific conductance, hardness, dissolved oxygen (DO), pH and the concentration of heavy metals. No significant changes occurred in water quality variables according to information presented in this analysis. Tobin and Hallowed (1990) found no evidence that toxic or undesirable substances were accumulating in the reservoir from 1985-1987.

Biologically related variables reviewed include channel morphology, habitat availability, invertebrate community composition, fish community composition (including endangered fish populations) and the White River's contribution to the Green River. Some of the highest catch rates for Colorado pikeminnow in the UCRB were immediately below TDD, which suggests aggregation of adults in this area. This may represent habitat quality, forage availability, or obstructed movement to upstream reaches. Both the fish community and invertebrate community substantially changed over time periods examined (Martinez et al. 1994; Wullschleger 1990). Prior to TDD, natives dominated the fish community in the Colorado section of the White River (> 75%). Following impoundment in 1984, nonnative fishes accounted for 40% to 80% of the fish community. Immigration of illicitly stocked piscivorus nonnative fish (e.g., black crappie, green sunfish, largemouth bass) from Kenney Reservoir into the Green River poses a particular threat to the young native fish concentrated in nursery habitat near the confluence of the Green and White rivers (Martinez et al. 1994), where non-native pressures are very high.

From a basinwide perspective, the White River plays an important role in stabilizing the Colorado pikeminnow population in the Upper Colorado River Basin. Natural recovery of this long-distance migratory species depends on protection and recovery of the remaining intact river corridors in the Colorado River system including tributaries. A stable population structure requires the presence of occupied and available habitat patches (Meffe and Carroll 1994). Therefore, any further degradation, fragmentation or loss of habitat (occupied or empty) in the Colorado River system may be detrimental to the future persistence of Colorado pikeminnow. For this reason, protection of the White River is crucial to overall stability of Colorado pikeminnow in the UCRB.

Physical, chemical, and biological changes over these time periods may be reasons for concern. Future monitoring and responsive management to offset impacts are necessary to prevent further harm to the native fish community in the White River. Water development projects should be operated to recover and maintain the ecological integrity of the White River for native fishes, in particular for the Colorado pikeminnow. Recommended actions to support this integrity include: recognizing the White River's contributions to the regional ecosystem; monitoring the physical, hydrologic, and biologic components of the White River; modifying releases to more closely mimic the historic hydrograph; and taking an adaptive management approach to river management, modifying strategies as additional information becomes available.

## LIST OF KEY WORDS

White River, Colorado pikeminnow, Taylor Draw Dam, Kenney Reservoir, water diversions, streamflow, suspended sediment, temperature, water quality, native fishes, nonnative fishes, invertebrates, habitat, water chemistry, hydrology, riverbed geomorphology.

# INTRODUCTION

The role that any river plays in the recovery of an endangered species requires an understanding of the environmental processes associated with the quantity and quality of habitats upon which that species depends. The presence of an endangered species within a river system is indicative of a disruption to those environmental processes. This is particularly evident in the Colorado River Basin. Most of the fish indigenous to the Colorado River Basin are in jeopardy; about 65% have legal status under the 1973 Endangered Species Act, as amended, and several others are protected by one or more of the basin states (Carlson and Muth 1993). These fish are adapted to the biological, chemical, and physical processes specific to the Colorado River Basin. Approximately 83% of the indigenous species are endemic (Carlson and Muth 1993). This high degree of endemism may have made them particularly prone to the effects of habitat alterations (Muth and Nesler 1993; Hawkins 1991; Hawkins and Nesler 1991). That is, it is unlikely that they evolved under the same environmental pressures as their non-endemic counterparts and they have not been as able to adapt to the current environmental changes. Within the Colorado River Basin, significant alterations to environmental processes have occurred through construction and operation of dams, diversions, and impoundments; point and non-point pollution; and the introduction of nonnative species (Behnke and Benson 1983). These alterations are the direct result of human activities that have taken place within the last 100 years. This report was prepared to assemble available information on the White River aquatic habitat and measurable changes that might have occurred there.

The White River is a tributary of the Green River in the Upper Colorado River Basin (UCRB: Figures 1a and 1b). It originates in the Rocky Mountains of northwestern Colorado. The headwaters are located in the Flat Top Mountains at an elevation exceeding 4,400 m (12,000 ft) above mean sea level (Boyle et al. 1984). The river flows westward for approximately 400 km (248 mi) draining more than 13,000 square kilometers (5,120 square miles), before it merges with the Green River in northeastern Utah (Figures 1a and 1b). In contrast to the headwaters, the confluence of the White and Green Rivers is located in the Colorado Plateau desert at 1,800 m (4,900 ft) above mean sea level (Boyle et al. 1984). Principal tributaries to the White River include the North Fork, South Fork, Yellow, Piceance, and Douglas creeks in Colorado, and Evacuation and Two Water Creeks in Utah (Figure 1a). All of these tributaries drain the southern portion of the basin.

The physical, chemical, and biological characteristics of the White River change as the river shifts from the mountains to the desert. Near river kilometer (RK) 115, the river transforms from a rhithron river that is typically clear, cool, and high gradient with coarse substrates (>76 mm), to a potamon river, more typical of desert rivers which are turbid, warm, low gradient, and sinuous with fine to medium substrates (<76 mm). Average annual precipitation in the White River basin generally increases with elevation and ranges from less than 18 cm/yr (7 in/yr) near the confluence with the Green River to over 67 cm/yr (26.4 in/yr) in the Flat Top Mountains (Utah Climate Center). Although precipitation is distributed evenly throughout the year, snowpack accumulation in the winter months is the main source of surface runoff in the spring (Boyle et al. 1984). White River basin geology is dominated by sedimentary rocks. These rocks, especially in the central and western sections of the basin, contain untapped oil-shale and coal reserves. Natural gas, oil, and uranium reserves are also present, although they are not as abundant (Melancon 1980).

Agriculture, including grazing, is the primary land use in the basin. Other uses include mining, industry, and recreation. Over 60% of the land is federally owned. The remaining 40% is owned by the private sector and the Uinta and Ouray Indian Tribes (Melancon 1980)
.

The following objectives were identified for this study:

1) Compile historic biological and physical data on the White River. This includes assimilating and evaluating information on the historic and present hydrologic conditions of the river including flow regime, water quality, habitat availability, and channel morphology, as well as evaluating whether the Taylor Draw Dam (TDD) and other water development projects have had measurable impacts on the White River.

2) Analyze features of particular importance to recovering the endangered fish. This includes identifying habitat used by endangered fish species in the White River and potential factors limiting recovery of these fish, unique hydrological conditions, and the physical and biological contributions of the White River to the Green River.

3) Identify elements of a long term monitoring program to insure protection of important features on the White River, and identify research needs which need to be met to enhance recovery of endangered fish populations.

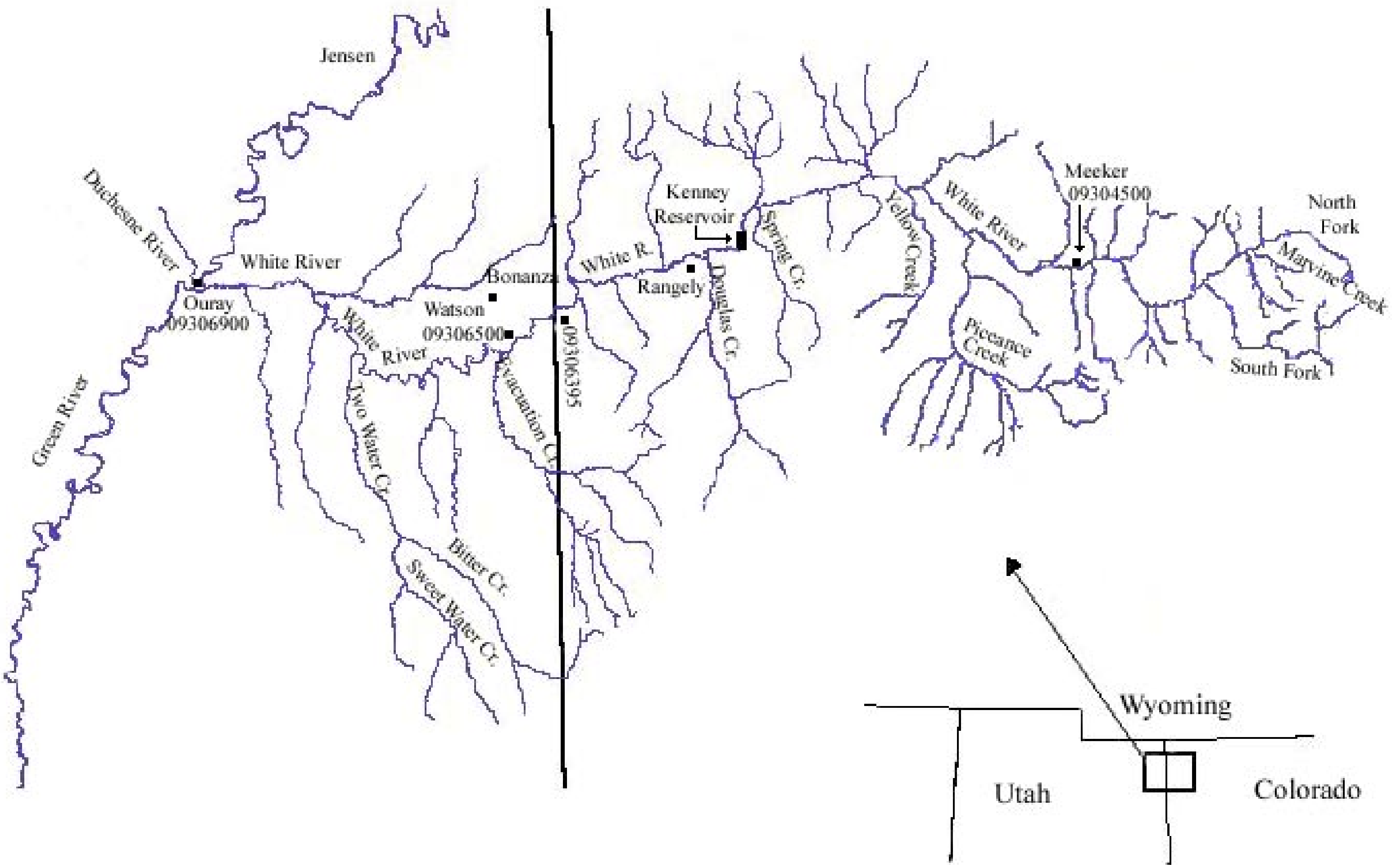



Figure 1a. White River Basin

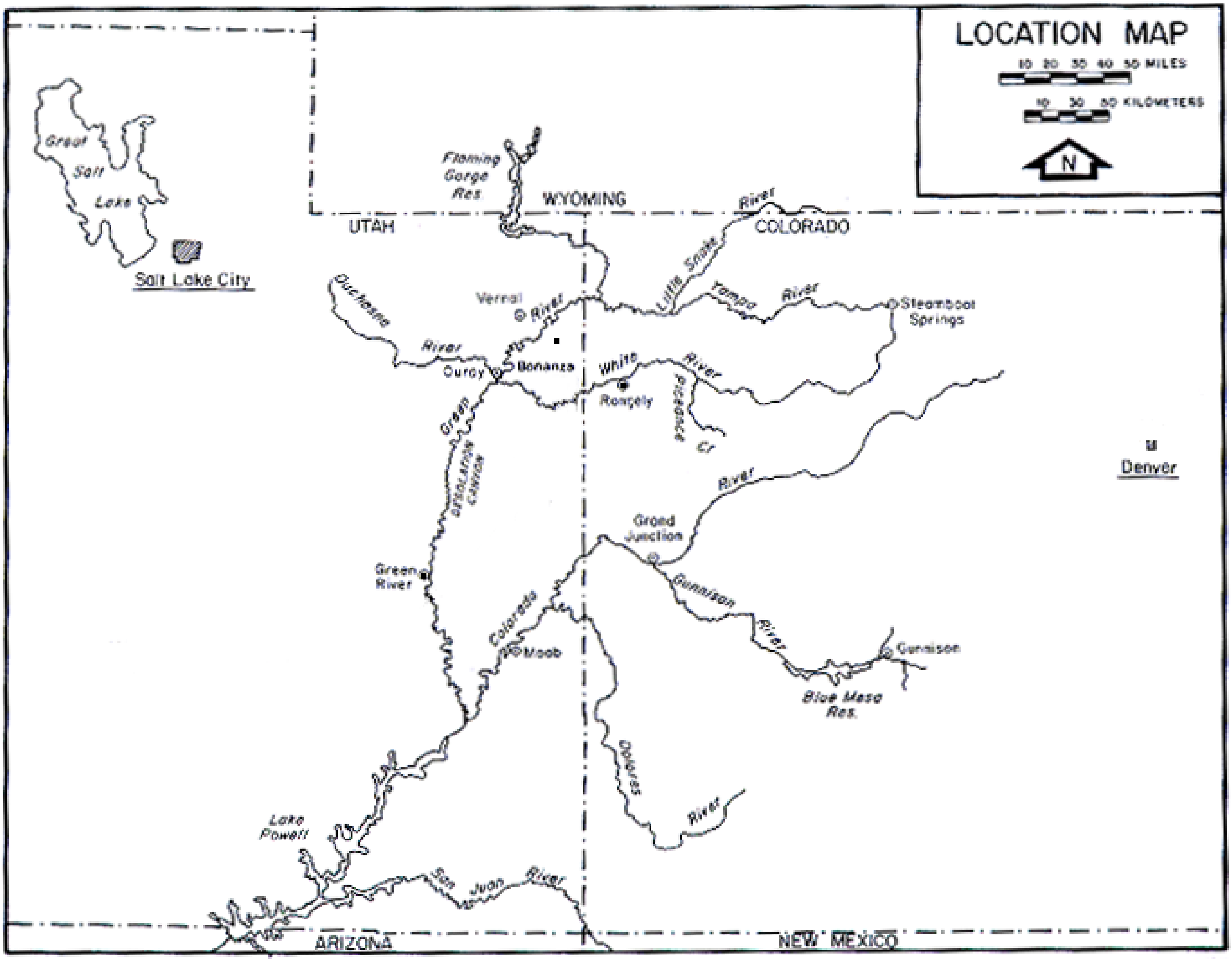



Figure 1b. Upper Colorado River Basin

## METHODS

Much of the information contained in this report was collected through an extensive literature review. The majority of the information was contained in unpublished reports prepared by governmental agencies and consulting firms in Colorado and Utah. Discharge and water quality data were obtained from United States Geological Survey (USGS) gage stations located throughout the UCRB (Figure 1b).

Data for the hydrological and chemical characteristics of the Duchesne, Green, White, and Yampa Rivers were obtained from 12 USGS gage stations (Table 1). Seven of these stations were located on the mainstem of the White River between Meeker, CO (RK 300), and the confluence of the White and Green rivers (RK 0). The remaining five stations were located on the Green, Yampa, and Duchesne rivers. The majority of data presented for the White River were compiled from the two stations with the longest period of record, USGS station 9306500, near Watson, UT, (39º 58" N, 109º 10" W) and USGS Station 9304500 near Meeker, CO (40º 02" N, 107º 51" W) (Figure 1a). The station at Watson had a period of record dating from 1923, and the station at Meeker had a period of record dating from 1909. Streamflow data from gaging station 9306395, located 15 km upstream from gaging station 9306500, were used to supplement flow data from 9306500 when necessary.

Information regarding historic dates of streamflow depletions was obtained from water rights appropriation data available from the State of Colorado's Division VI Water Resources and the State of Utah's Division of Water Rights databases. These data were utilized to estimate changes in discharge due to irrigation diversions in an attempt to reconstruct the natural hydrograph of the White River. Because irrigation diversions on the White River began as early as 1870, no reliable method is available to assess the completely free run of the river, and potential early diversion impacts on the natural flow regime of the river. The available streamflow data were divided into three time periods to detect hydrologic changes with development based on McAda and Kaeding (1990). The water years for comparing the White to other rivers were categorized into early development (1895-1945), middle development (1946-1984), and post Taylor Draw Dam development (1985-2000) periods. Data were not available for all stations in all years. While the earliest time period probably underestimates the historic discharge during non-runoff periods, it provides a reasonable estimate of natural flows when only a small portion of water was diverted (McAda and Kaeding 1990). It is important to note that mean monthly discharge data used in this study does not account for daily flow variations which are an important element of riverine ecology (Stanford 1993).

Annual precipitation measurements from the Utah Climate Center were used to assess changes in precipitation which might affect streamflow. Four different weather stations were identified throughout the White River basin to accurately document variations in total precipitation. The stations in Utah were Ouray 4 NE and Bonanza; the stations in Colorado were Meeker 2 and Marvine Ranch (Figure 1a).

Table 1. U.S. Geological Survey stations of the Upper Green River Basin, Utah and Colorado.

| Station number | Name | Elevation (m) | Drainage area (sq km) | POR* (YRS.) | Mean discharge (cfs) |
|---|---|---|---|---|---|
| 0925100 | Yampa near Maybell | 1,788 | 8,871 | 83 | 1,585 |
| 09260050 | Yampa Deerlodge Park | 1,715 | 19,927 | 9 | 2,286 |
| 09302000 | Duchesne Randlett | 1,441 | 11,048 | 53 | 553 |
| 09261000 | Green River Jensen | 1,224 | 77,160 | 52 | 4,362 |
| 09315000 | Green River Green River | 1,231 | 104,950 | 100 | 6,273 |
| 09304500 | White River Meeker | 1,909 | 1,964 | 91 | 628 |
| 09304800 | White River below Meeker | 1,796 | 2,664 | 38 | 673 |
| 09306290 | White River Boise Creek | 1,635 | 6,592 | 17 | 812 |
| 09306300 | White River Rangely | 1,644 | 7,213 | 10 | 653 |
| 09306395 | White River Stateline | 1,524 | 9,573 | 9 | 823 |
| 09306500 | White River Watson | 1,499 | 10,457 | 72 | 706 |
| 09306500 | White R. Ouray | 1,411 | 13,319 | 12 | 852 |

* POR-Period of record

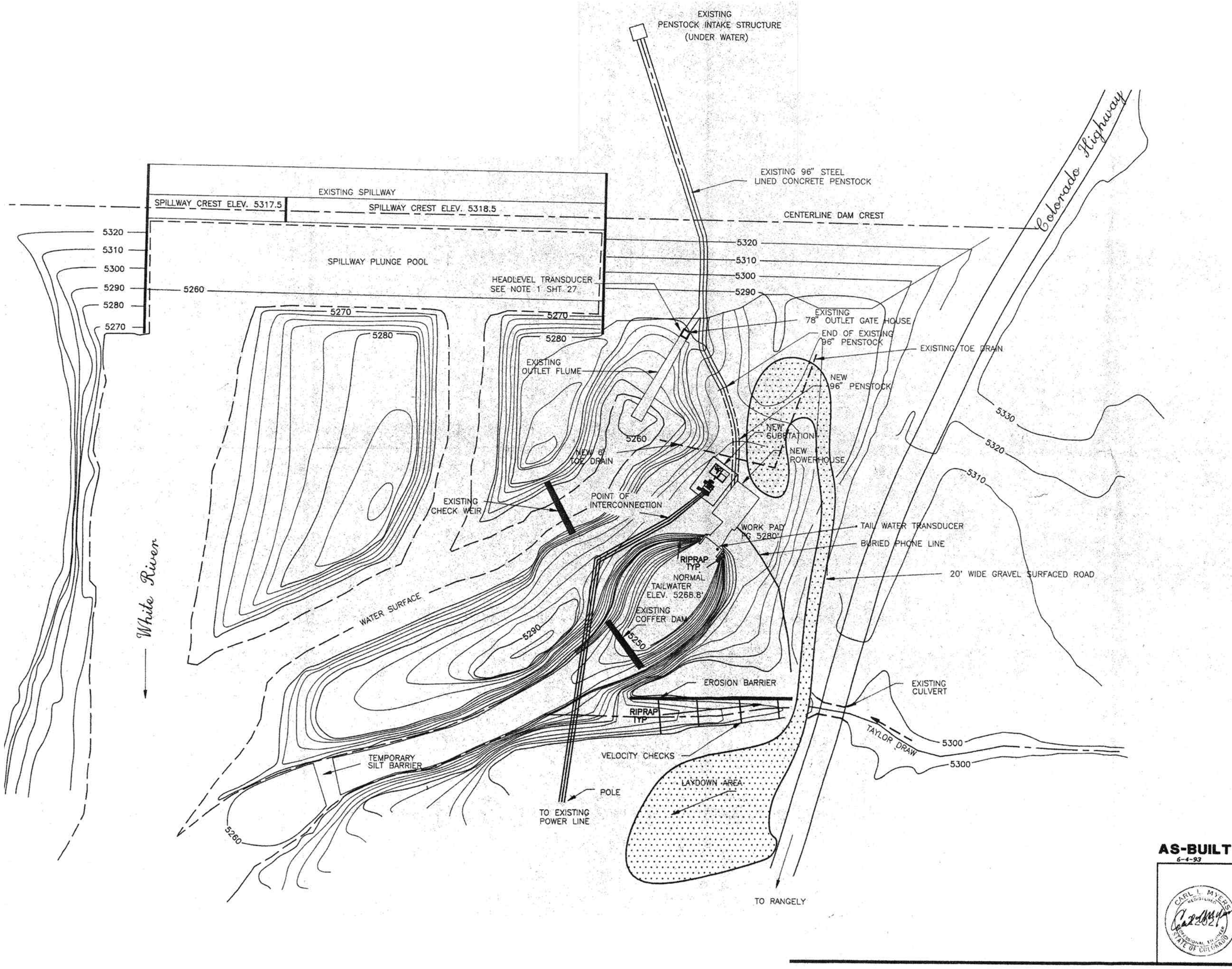
## WATER USES AND DEPLETIONS

Water has been diverted from the White River since the late 1800's. Water uses have included irrigation, municipal, industrial, fishery, domestic, livestock, recreational, and, most recently, power generation (Table 2). Most of the diverted water is used for irrigation (Colorado Division of Water Resources 1994). By 1900, more than 20 irrigation projects had been started on the White River. Water depletion from these projects was usually small, resulting in an average depletion of 8.5 cfs (range 0.3-57.7 cfs) from June through September. Average diversion from the White River from 1996 to 1999 (water years) was 729,196 AF (Table 2) (Colorado Division of Water Resources 1994). Only 59% of diverted water is consumed; the remaining is returned to the river (Table 2; Colorado Division of Water Resources 1994).

The first large diversion on the White River was for Rio Blanco Lake, an off-stream impoundment built in 1965 by the Colorado Division of Wildlife. This reservoir, located at RK 243 (RM 151), covers 116 surface acres (Martinez 1986). The main stem of the White River was not impounded until October 1984 when Taylor Draw Dam (TDD) was constructed approximately 16 km (10 mi) east of Rangely, CO (Figure 2). The dam was originally 21.6 m above the streambed. It was raised 2 m, or 23.6 m above the streambed, in 1992. By 1994, the Kenney Reservoir impounded by the dam, had a maximum surface area of 616 acres (275 ha), a maximum depth of 15.2 m and a volume of 17 million cubic meters at full capacity (Martinez et al. 1994). The reservoir inundated ten kilometers of the mainstem river. Kenney Reservoir provides a municipal and industrial water supply to the town of Rangely, limited flood control, and recreational opportunities ("Biological Opinion-Taylor Draw Reservoir Project" letter from U.S. Fish and Wildlife Service to Army Corps of Engineers 1982).

Kenney Reservoir is operated by the Rio Blanco Water Conservancy District, primarily as a run-of-the-river project with outflow from the dam equaling inflow to the reservoir. During drought years, the dam is required to release a minimum of 200 cfs, or natural flow, whichever is less. Although the dam is operated such that inflow equals outflow, evaporation from March through October causes some depletion, estimated at 0.37% annually (USFWS 1982). Evaporative depletion from 1992-1994 averaged 1643 af (Table 3; Colorado Division of Water Resources 1994). The cumulative annual depletion from the river (diversion depletions and evaporation depletions) from 1992 to 1994 was 52,572 AF or 11.4% of the total basin yield (Table 3). These data illustrate that evaporative depletion is considerably less than loss from diversions.

In the spring of 1993, a non-peaking hydroelectric power plant was added to the Taylor Draw Dam providing 11,225,000 kilowatt hours (kWh) of electrical energy per year to Moon Lake Electric Association, Inc. This turbine generator has a hydraulic capacity of 500 cfs and a rated capacity of 1.6 MW. The project is located approximately 60 meters downstream of Taylor Draw Dam (Environmental Assessment for Taylor Draw Hydroelectric Project FERC No. 8914-000-Colorado). Under the Memorandum of Agreement (MOA), the hydroelectric plant is, and will continue to be, operated as an instantaneous run-of-the-river project year-round, with discharge immediately downstream of the tailrace equaling inflow into Kenney Reservoir (Environmental Assessment for Taylor Draw Hydroelectric Project FERC No. 8914-000-Colorado). The hydroelectric generator at Taylor Draw Dam experienced start-up problems which caused some erratic flow fluctuations during its first year of operation (Terry Ireland, U. S. Fish and Wildlife Service, personal communication, 1994).




| REV | DESCRIPTION | BY | DATE |
|---|---|---|---|
| 4 | AS BUILT | CY | 6/93 |
| 3 | RELOCATE SUBSTATION | CY | 6/92 |
| 2 | LOCATE HD. LVL. XDUCER | CY | 5/92 |
| 1 | GENERAL REVISIONS | CY | 4/92 |

SITE PLAN

TAYLOR DRAW HYDROELECTRIC PROJECT

| SCALE | DRAWN BY | DRAWING NO. |
|---|---|---|
| 1"=50 FT. | C.Y. | 151-1-02 |
| DATE MAR. 13, 1992 | CHECKED BY | |

MYERS ENGINEERING COMPANY, P.A.
Consulting Engineers
750 WARM SPRINGS AVE. BOISE, IDAHO 83712 TELEPHONE:(208) 338-1425

SHEET NO. 3 REV. 4

Table 2. Summary of diversions, depletions and basin yield, White River Colorado, 1996-1999.

| YEAR | BASIN YIELD (AF) | Amount of Water Diverted by Use (AF) | | | | | | | | Amount of Water Consumed (AF) | Amount of Water Diverted (AF) | Percent of Yield Consumed (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Irrigation | Municipal | Industrial | Fishing | Domestic | Livestock | Power | Other | | | |
| 96 | 595,904 | 292,474 | 2,500 | 1,721 | 11,582 | 464 | 13,110 | 470,791 | 606 | 41,075 | 793,248 | 6.9 |
| 97 | 732,359 | 243,861 | 1,578 | 3,044 | 27,376 | 1,174 | 13,760 | 460,172 | 610 | 30,102 | 751,575 | 4.1 |
| 98 | 786,325 | 295,516 | 2,320 | 2,531 | 25,491 | 813 | 15,670 | 453,557 | 652 | 35,545 | 796,550 | 4.5 |
| 99 | 592,988 | 256,494 | 2,272 | 2,304 | 24,827 | 841 | 18,141 | 269,984 | 547 | 38,389 | 575,410 | 6.5 |
| avg | 676,894 | 272,086 | 2,168 | 2,400 | 22,319 | 823 | 15,170 | 413,626 | 604 | 36,278 | 729,196 | 5 |

Table 3. Evaporation from Kenney Reservoir and total depletions from the White River, 1996-1999.

| Year | Basin Yield | Evaporation (AF) | Percent Depleted from Evaporation | Total Depletions (Evaporation + Consumption) | Total Percent River Depleted (Evaporation +Consumption) |
|---|---|---|---|---|---|
| 1996 | 535,904 | 1,342 | .23 | 42,417 | 7.12 |
| 1997 | 732,359 | 1,228 | .17 | 31,330 | 4.28 |
| 1998 | 786,325 | 1,396 | .18 | 36,941 | 4.7 |
| 1999 | 592,988 | 1,152 | .19 | 39,541 | 6.67 |
| Avg | 676,894 | 1,279 | .19 | 37,557 | 6 |

## HYDROLOGY

Hydrographs for rivers in the Green River Basin are characterized by seasonal fluctuations, with peak flows occurring in the spring when the snowpack melts. While the Green, Yampa, Duchesne, and White rivers exhibit similar hydrological patterns, the total volume of water and timing of discharge differs between the rivers. The average annual streamflow of the Green River, as measured at the Green River gaging station (POR 100 yrs), was the greatest at 6,273 cfs, with peak streamflows occurring in May and June (USGS 9215000, Green River). The White River is the second largest tributary to the Green River, contributing about 25% as much flow as is added to the system by the largest tributary, the Yampa River. Average annual discharge for the Yampa River, as measured near Maybell, CO (POR 83 yrs), is 1,585 cfs, but further downstream on the Yampa at Deerlodge (POR 9 yrs), below the confluence with the Little Snake River, the mean annual flow is 2,286 cfs. Annual discharge from the Yampa River is considerably greater than the White River at Watson (POR 72 yrs), 706 cfs, and the Duchesne River at Randlett (POR 53 yrs), 553 cfs. The Yampa River also peaked slightly earlier than either the White or Duchesne rivers (Figure 1a; Table 1).

At the mouth of the White River, approximately 65% of the annual flow occurs in May, June, and July with runoff increasing in late April, and flows usually reaching a peak during the first two weeks of June (Boyle et al. 1984). The mean monthly streamflow was highest in June, followed by May (Figure 3). Streamflow decreased rapidly in July as snowpack melted and continued to decline into December. Baseflows (Nov-Feb) typically averaged 300 to 400 cfs. The highest mean daily streamflow on the White River at Watson record was 8,160 cfs on July 15, 1929, while the lowest was 13 cfs on July 3, 1977, a severe drought year.

Spring, summer, and fall rain storms had a significant, yet ephemeral, impact on flow. For example, during a storm event in August, 1943, streamflow at Meeker increased from 315 cfs to 3,050 cfs in 2 days (USGS station 9306500). At the Meeker station (RK 300), the mean annual streamflow for the period of record (Table 1) was 628 cfs, with an average annual yield of 451,100 AF. The highest mean daily streamflow was 6,320 cfs recorded on May 25, 1984, and the lowest was 78 cfs recorded on July 16, 1977. The temporal discharge distribution, as shown by flow duration curves, also varied between basins (Figure 4). In the middle Green River Basin the Yampa River provides the greatest quantity of water, the White River provides the most consistent year round flows, and the Duchesne River provides the lowest quantity of water (approximately 600,000 af has been depleted from the Duchesne). The 50% duration discharge for the Yampa River at Maybell (POR 83 years) was 408 cfs. The 50% duration discharge for the Duchesne River at Randlett (POR 53 yrs) was 352 cfs. The 50% duration discharge for the White River at Watson (POR 72 years) is 451 cfs, which is 10% higher then the 50% duration flow on the Yampa and 28% higher then the 50% duration flow on the Duchesne (Figure 3). Similarly the 95% duration discharge for the White, Yampa and Duchesne rivers are 240 cfs, 130 cfs and 38 cfs respectively. The White River's 95% duration discharge is 86% higher than the Yampa River's and over 500% greater then the Duchesne River's 95% duration discharge. In contrast, the 5% duration discharge for the White, Yampa, and Duchesne rivers are 2,187 cfs, 7,298 cfs and 1,998 cfs, respectively. The Yampa River has considerably higher peak flows (234%) and greater seasonal variation then the White River.

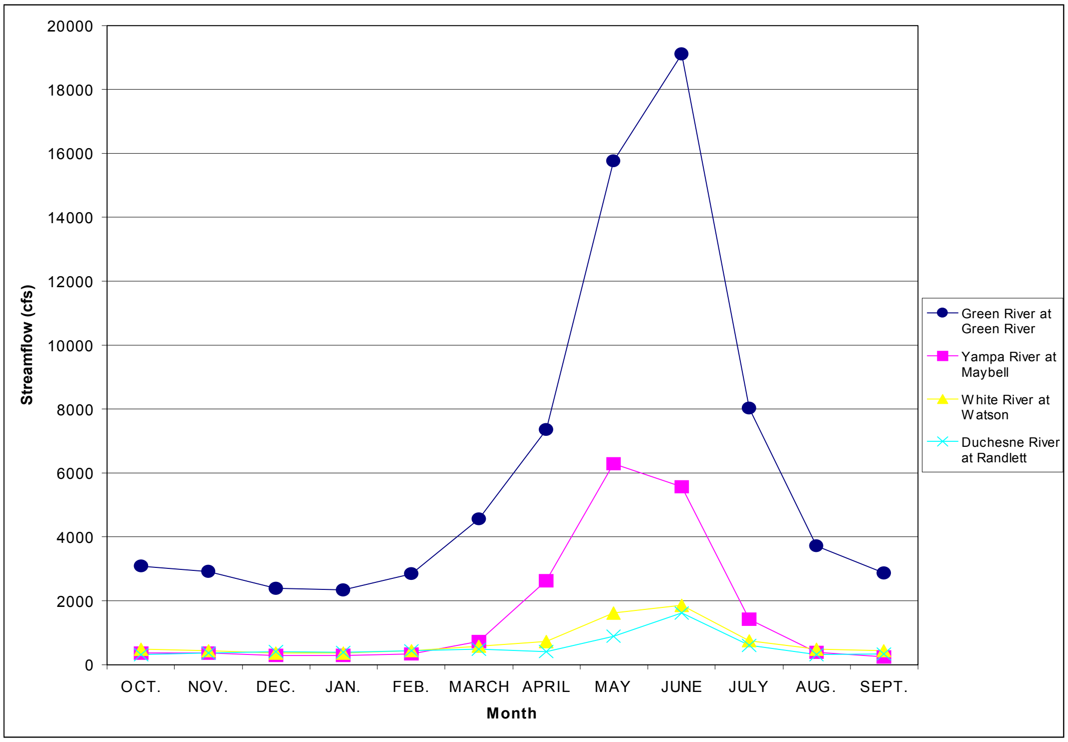



Figure 3. Hydrographs for rivers in the middle Green River Basin.
(POR: Green, 1895-2000; Yampa, 1916-1999; Watson, 1923-1999; Duchesne, 1946-1998

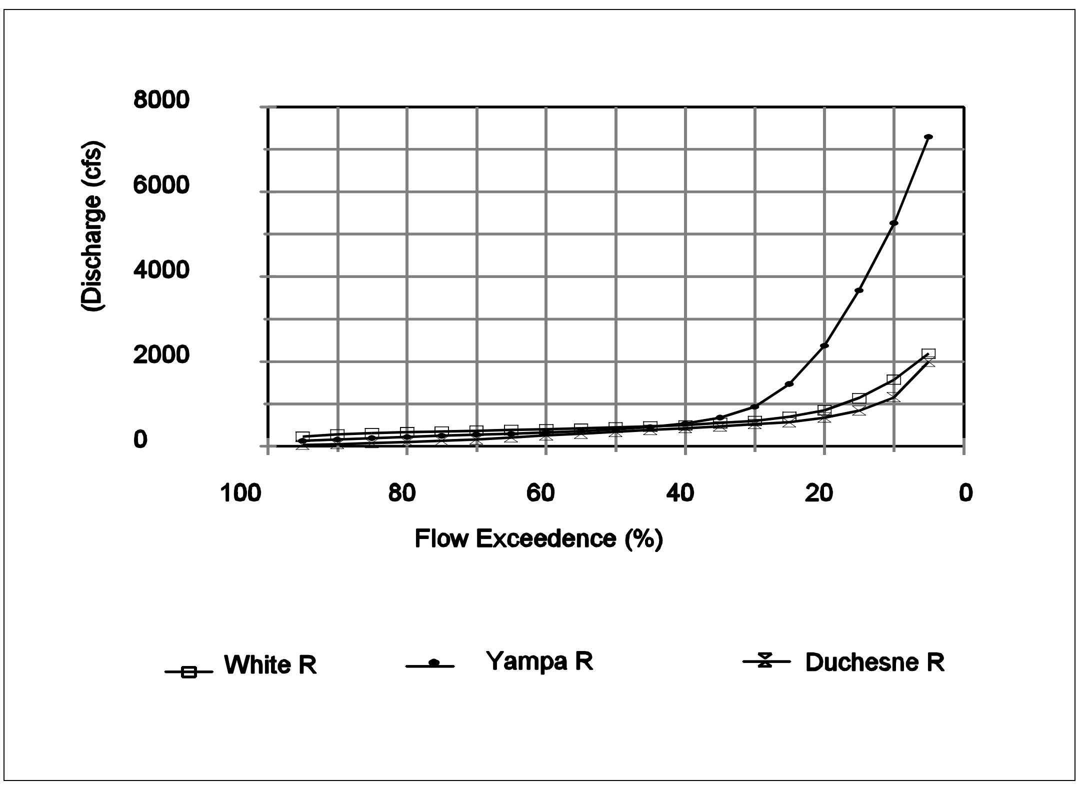



Figure 4. Flow exceedence curves for the White, Yampa, and Duchesne Rivers.

Mean monthly streamflows during the three time periods at the Meeker and Watson gages exhibit distinct differences when comparing the two sites (Figures 5 and 6). At the Meeker, CO gage, above Kenny Reservoir, base flows are relatively consistent in the 20th Century, but spring flows have decreased approximately 10% during the most recent 15 years (Figure 5). Below TDD, the changes in the flow regime are more marked. Generally, the base flows at Watson, UT are higher in the most recent period, falling behind the early period in April. However, in the most recent period, spring runoff flows have increased when compared to the middle development period, and the June and July mean monthly flows from 1986-1999 are at or above the highest recorded. Despite increasing diversions, the White River appears to be delivering similar flows to the Green River in the last 13 years as it did from 1923-1945. Increased average precipitation and/or irrigation return flows in the most recent era, then, must have more than made up for the total volume withdrawn. Weather variables are, however, unlikely to constitute a dependable contribution to the system which can be relied upon to support increased withdrawals. In addition, the characteristics of the water released below the dam have changed dramatically from the historic condition, particularly the sediment load and temperature.

Precipitation data from four weather stations (Ouray 4 NE, Bonanza, Meeker 2, and Marvine Ranch) (Figure 1a) were analyzed to determine the cause for hydrologic discrepancies in the three periods. Monthly and annual precipitation data records were available from 1941 to 1995 at the Ouray 4 NE station, from 1938 to 1995 at the Bonanza station, from 1971 to 1992 at the Meeker 2 station and from 1972 to 1995 at the Marvine Ranch. The highest average annual precipitation was 67.0 cm/yr (26.4 in) at Marvine Ranch; the lowest was 17.2 cm/yr (6.8 in) at Ouray (Table 4). Precipitation data from Marvine Ranch, located in the Flat Top Mountains, was the best indicator of annual snowpack and the ensuing annual discharges. Snowpack and melting regimes are the primary determinants for the timing, quantity, and duration for the spring runoff. Overall, spring runoff corresponded to the snowpack and spring temperatures at the Marvine Ranch.

At the Meeker station maximum flows of 4,500 to 5,000 cfs occur every 10 to 20 years and 6,000 to 7,000 cfs every 30 to 80 years (Figure 7). Three of the five largest floods occurred in 1983, 1984 and 1995 (Figure 7). Diversions apparently had negligible effects on spring flood hydrology. Climatic conditions were primarily responsible for the lower mean monthly averages for May and June in the post TDD period.

Flood frequency analysis was used to determine the average recurrence interval between floods. For the White River at Watson, maximum flows of 5,000 cfs occurred every 10 years, 6,000 cfs floods every 30 to 40 years, and greater than 6,000 every 50 to 100 years (Figure 8). The highest discharge (over 8,000 cfs) occurred in 1929; ten to twenty year floods (approximately 5,000 cfs) occurred in 1952, 1957, 1962 and most recently in 1995 (Figure 8). There were two 20 to 40 (1983 and 1984) year floods and one 10 to 20 (1995) year flood during the period 1983-1995. The recent flood events suggest that diversions did not significantly disrupt natural spring runoff cycles. Most water is diverted following spring runoff. Since completion of Taylor Draw Dam in 1985, there was one 10 to 20 year flood (1995) and two 7 to 9 year floods (1985 and 1993) (Figure 8).

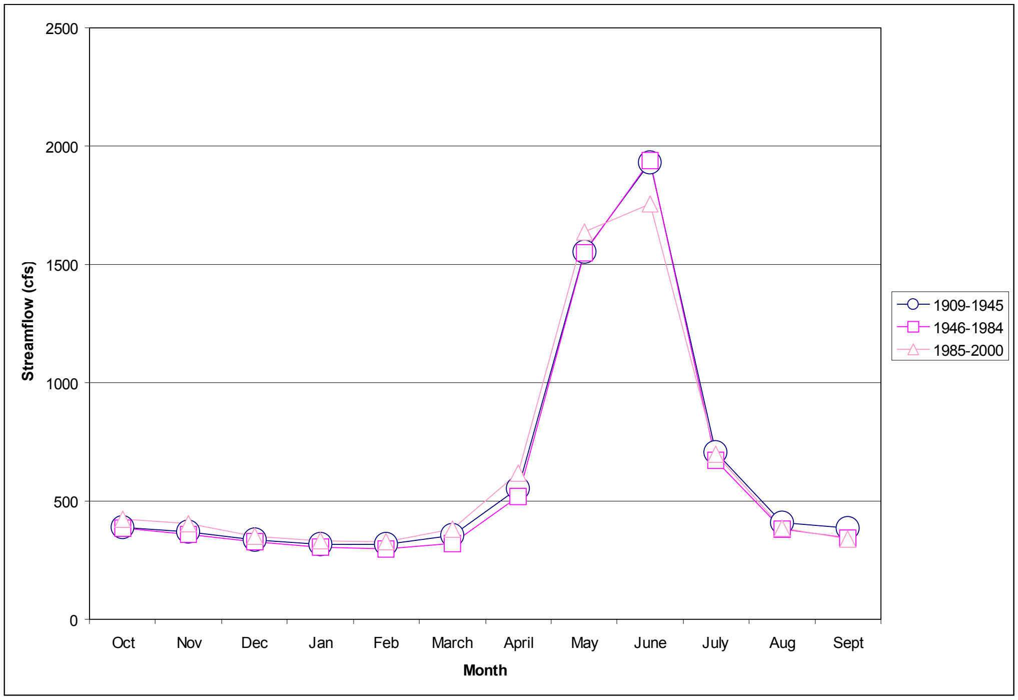



Figure 5. Comparison of mean monthly stream flows (cfs) in the White River at Meeker for three time periods: 1)1909-1945, 2) 1946-1984, 3) 1985-2000

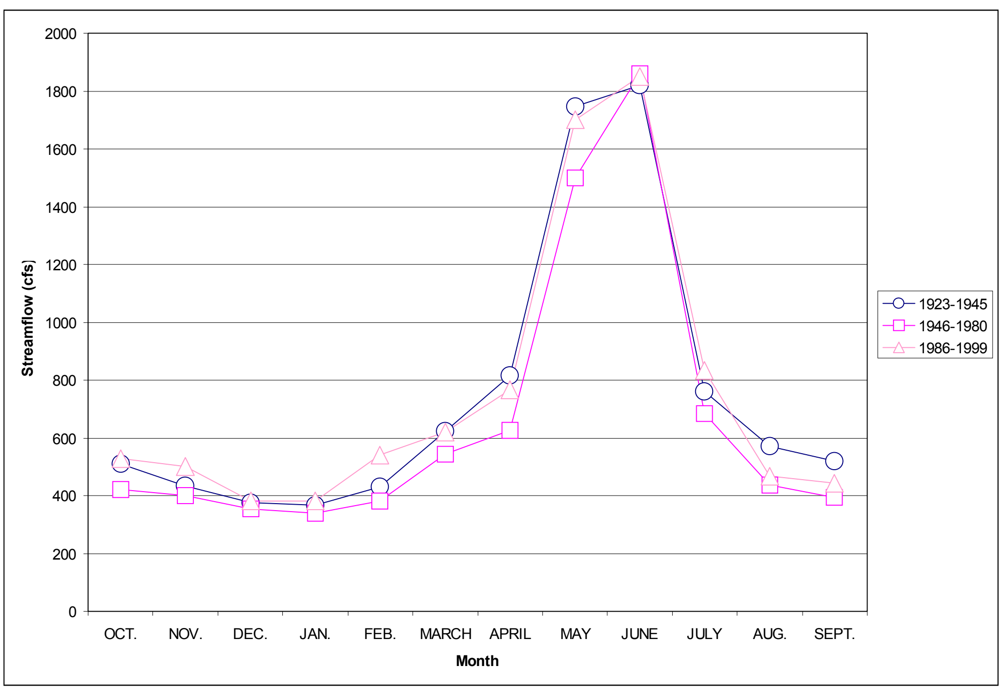



Figure 6. Comparison of mean monthly stream flows (cfs) in the White River at Watson for three time periods: 1)1923-1945, 2) 1946-1980, 3) 1986-1999

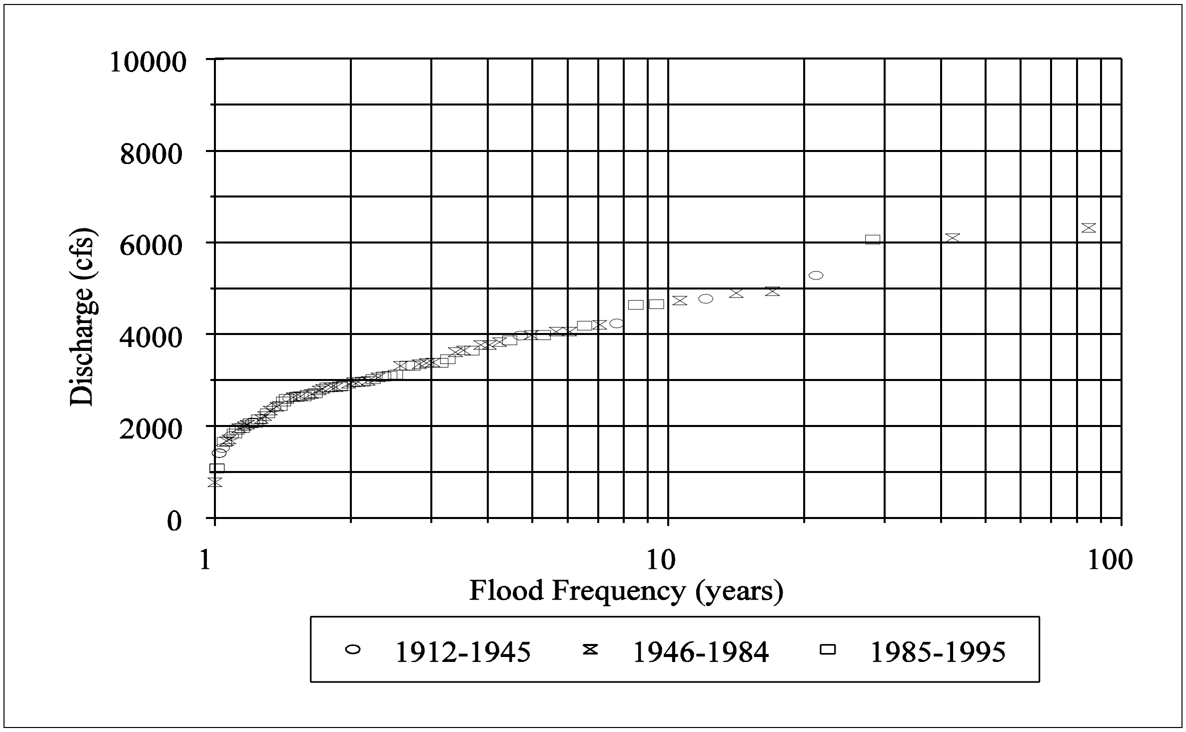



Figure 7. Flood frequency at Meeker for the three development periods.

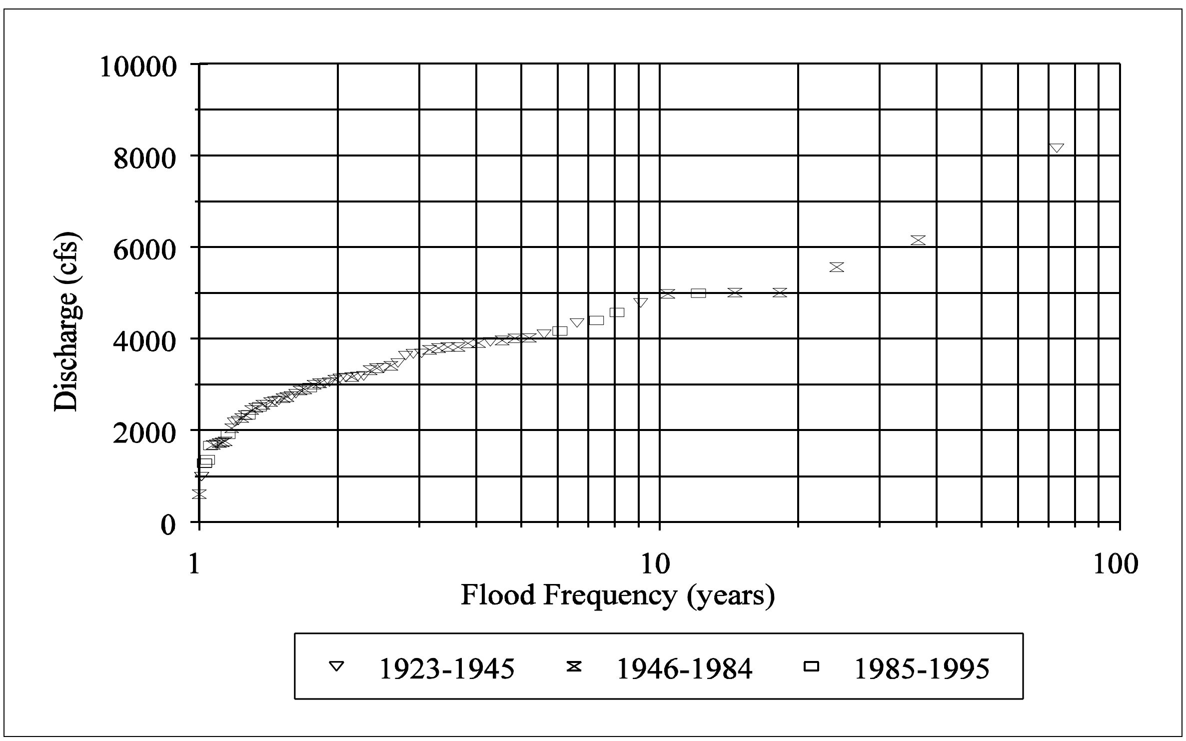



Figure 8. Flood frequency at Watson for the three development periods.

Table 4. White River Basin precipitation, for the POR of each station.

| Station | Ouray 4 NE | Bonanza | Meeker 2 | Marvine Ranch |
|---|---|---|---|---|
| Month | Precipitation in inches | | | |
| Jan | 0.38 | 0.57 | 0.70 | 2.42 |
| Feb | 0.32 | 0.43 | 0.74 | 2.38 |
| Mar | 0.48 | 0.70 | 1.39 | 2.82 |
| Apr | 0.65 | 0.79 | 1.38 | 2.06 |
| May | 0.69 | 1.03 | 1.52 | 2.31 |
| Jun | 0.53 | 0.73 | 0.93 | 1.53 |
| Jul | 0.64 | 0.86 | 1.39 | 2.00 |
| Aug | 0.73 | 0.90 | 1.22 | 1.90 |
| Sep | 0.68 | 0.83 | 1.15 | 1.95 |
| Oct | 0.89 | 1.07 | 1.77 | 2.10 |
| Nov | 0.42 | 0.49 | 1.09 | 2.35 |
| Dec | 0.39 | 0.49 | 0.86 | 2.60 |
| Avg | 6.79 | 8.87 | 14.14 | 26.42 |

Comparison of the annual daily mean, minimum and maximum between Meeker and Watson during the three development periods reveals similar trends (Table 5). Daily mean has returned to mean historic levels, but maximum flows have decreased dramatically. A 21% overall decrease in maximum flows was measured at Meeker, and a nearly 43% decrease at Watson. Because Taylor Draw Dam is operated as a run-of-the-river facility, the calculated decreases are likely strongly influenced by comparing two time periods of different duration (e.g., 1923-45 vs. 1985-98 for Watson), and the occurrence of five years of drought in the latter time period. Reduced flows decrease the river's ability to flush fine sediments from substrate interstices, which are important for native fish breeding.

We determined the timing, duration, and overall quantity of water that the White River contributes to the Green River. The data collected indicate that the White River historically contributed 11% of the Green River flow, as measured at Green River, Utah. With the post-development flow reductions in the Green and its tributaries, the White River volume now constitutes 14% of the total, though it is still less than the Yampa River's contribution (Table 6). A comparison between the early and post TDD periods indicates the White River contributes a greater portion of the spring runoff then it did historically. This can be attributed to impoundment of the Green River at Flaming Gorge in 1964 which has reduced the spring runoff and flooding on the Green River, and to increased withdrawals. This increases the White River's importance to the maintenance of the Green River system and Colorado pikeminnow population than it was historically.

Table 5. Comparison of annual daily mean, maximum and minimum discharge on the White River for three development periods.

| Development period | Streamflow (cfs) | | | Percent change in average mean monthly flow (%) | | Percent change in annual yearly maximum flow (%) | |
|---|---|---|---|---|---|---|---|
| | Mean | Min | Max* | Period to period | Early to post TDD | Period to period | Early to post TDD |
| USGS Station near Meeker | | | | | | | |
| 1909-1945 (early) | 634 | 112 | 6,070 | | | | |
| 1946-1984 (middle) | 618 | 78 | 6,320 | -2.6 | | 4.0 | |
| 1985-1999 (post TDD) | 648 | 93 | 5,030 | 4.6 | 2.2 | -26 | -21.0 |
| USGS Station near Watson | | | | | | | |
| 1923-1945 (early) | 751 | 53 | 8,160 | | | | |
| 1946-1979 (middle) | 664 | 13 | 5,010 | -13.1 | | -61.4 | |
| 1985-1998 (post TDD) | 749 | 65 | 4,660 | 12.8 | -0.3 | -7.0 | -42.9 |

* Maximum spring runoff flows

Table 6. Tributary contributions to volume of the Green River for three time periods.

| | POR | ≤1945 | % | 1946-1984 | % | ≥1985 | % |
|---|---|---|---|---|---|---|---|
| Green River at Green River | 1895-2000 | 6806 | | 5931 | | 5509 | |
| White River at Meeker | 1909-2000 | 635 | | 617 | | 638 | |
| White River at Watson | 1923-1999 | 763 | 11 | 650 | 11 | 751 | 14 |
| Yampa River at Maybell | 1916-1999 | 1629 | 24 | 1539 | 26 | 1617 | 29 |
| Duchesne River at Randlett | 1946-1998 | 693 | 10 | 593 | 10 | 437 | 8 |

% = Percent of Green River volume at Green River, Utah contributed by indicated tributary for indicated period of record (balance of total is made up by other tributaries, basin runoff, and the mainstem Green River).

## CHANNEL MORPHOLOGY

Data for White River channel morphology were obtained from observational discharge notes at the Watson station. Notes have been summarized on a monthly basis since 1968; they include average width and average area measurements of the river channel at that station. Width and area data from individual notes were used only if measured at a known marker. At the Watson station, these markers were either the gage or cable located approximately 46 m (150 ft) above the gage.

Several studies (Chart 1987; Miller et al. 1982; Carlson et al. 1979) analyzed channel morphology of the White River by examining channel transects. The first quantitative channel transect analysis of the White River was conducted by Carlson et al. (1979) from 1975-1977. This study presented data on width, depth, substrate velocity, and gradient at two different sampling stations (RK 240 and RK 170). River reaches were described as relatively high velocity with medium to large substrates. Width to depth ratios were small, reflecting the higher velocity nature of these two river segments. Hydraulic habitat in these areas was dominated by riffles.

Information on habitat availability was summarized from a literature review. Habitat availability by river kilometer was based on river reaches delineated by Miller et al. (1982). Miller et al. (1982) divided the river into five sections. Each section was evaluated for parameters of hydraulic habitat, average depths, substrates, surrounding topography and conductivity. In the two downstream sections (RK 0 to 95) which flow through alluvial plains and low canyons, hydraulic habitat types included backwaters, eddies, side channels, pools, backwaters and riffles with no rapids. Sand and silt were the most common substrates. The third section (RK 95 to 151) flows through a deep canyon with several side drainages. This section contained the greatest hydraulic habitat diversity. Section 3 had the steepest gradient with cobble and gravel substrates. The fourth section (RK 151 to 213) meanders through a broad valley. Hydraulic habitat types included backwaters, side channels, eddies, riffles, isolated pools, and rapids. The most upstream section (RK 213 to 241) flows through shallow canyons bordered with pinion and juniper. The primary hydraulic habitat types were riffles and runs. This reach had cobble and gravel substrates and low turbidity.

More recently, Chart (1987) examined 18 transects: 10 below the dam and 8 above. Physical characteristics of these transects were similar to those described by Miller et al. (1982), suggesting that channel morphology has not changed significantly. Both Miller et al. (1982) and Chart (1987) reported that high discharge events (due to spring discharge and storm events) modified habitat more than baseflows. Channel degradation below TDD due to reduced sediment loads has not been evaluated since 1987.

Width to depth ratios at the Watson gage averaged 68.9 from 1971 to 1993 (Figure 9). A comparison among years suggests that this index did not change substantially since the early 1970's. Channel shape, as represented by width-to-depth ratio, varied with discharge at the Watson station. During periods of high streamflow, average channel depth increased, thereby lowering width-to-depth ratio.

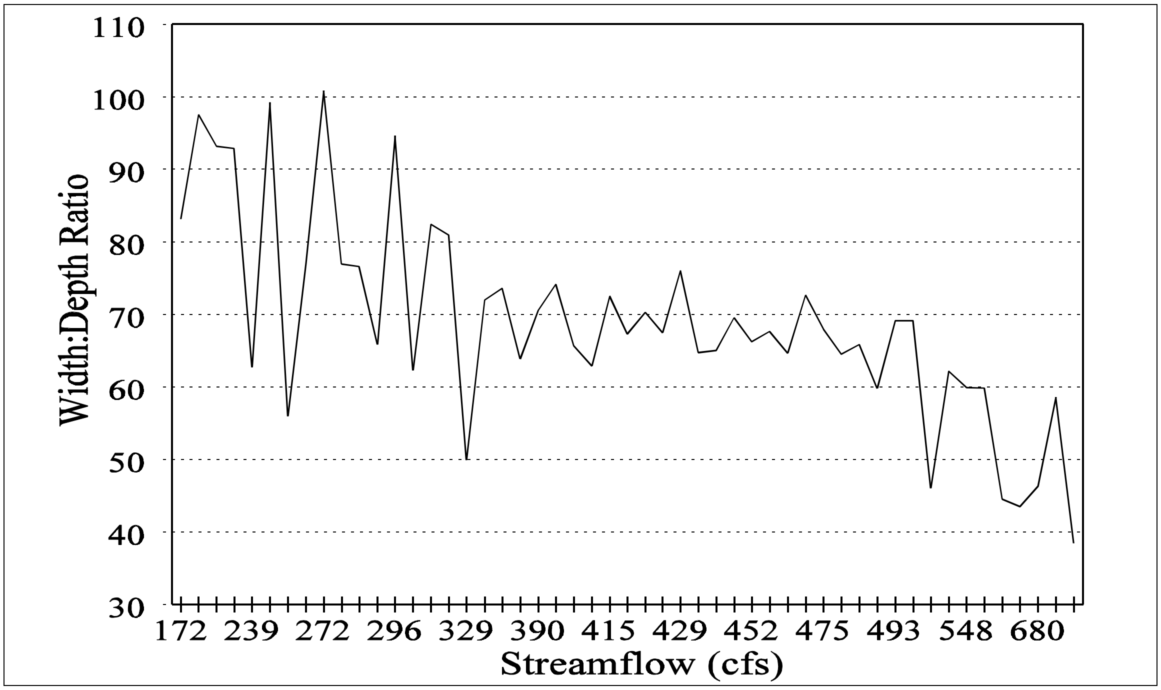


Figure 9. Discharge vs. channel shape, Watson station.

## WATER QUALITY

Daily water quality data for the White River was obtained from USGS stations, 9306500 (Watson), 9304500 (Meeker) and 9306900 (Ouray). Data available daily usually included temperature, suspended solids, and specific conductance; other water quality components (DO, pH, hardness, trace elements, etc.) were summarized monthly or quarterly.

Physical and chemical characteristics of the White River were compared with those of other upper Green River tributaries (Yampa, Duchesne, and Green rivers) to assess the contributions of each of these tributaries to the Green River ecosystem.

### *Temperature Regime*

Green River Basin thermographs were similar among weather stations with temperatures remaining near 0ºC in the winter and peaking during the summer months (Figure 10). The Yampa River thermograph (Maybell station) was nearly identical to that of the White River (Watson station). The Duchesne River (Randlett station) was warmer than both the White and Yampa rivers with temperatures rising more rapidly in the spring and remaining higher throughout the summer. Hypolimnetic draws from Flaming Gorge prevented the Green River from freezing during the winter months and from attaining historical highs during the summer months (Jensen station). The highest temperatures occurred during summer months after spring runoff at all stations.

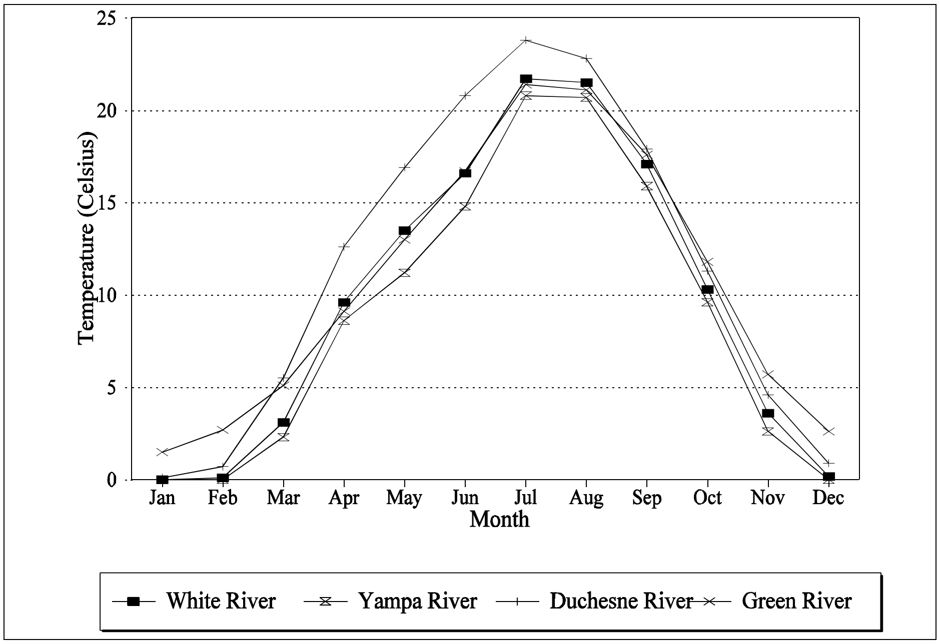



Figure 10. Comparison of Green River Basin thermographs.

Daily water temperature data were available from 1964 to 1993 at the Watson station, although several periods were incomplete. Historically, the river was frozen throughout winter months (mid-November through early March). Beginning in late February and early March, ice would melt and water temperatures would steadily increase to maximum temperatures of 20-23ºC occurring in July through mid-August. The highest temperature recorded at the Watson station was 29.6ºC in July, 1989.

Degree days (average monthly temperature * number of days in a month) averaged over 600 in summer months (June, July, and August), 250-500 in the spring and fall months (March, April, September, and October), and less than 100 during winter months (November through February). Annual degree days (sum of all the monthly total of degree days) ranged from a low of 2,500 in 1971 to approximately 4,000 in 1981 (USGS 9306500).

The Environmental Impact Statement issued for Kenney Reservoir predicted temperature decreases in the river reach directly below the dam because of hypolimnetic draws (USFWS 1982). During high flow years, as measured in July, a temperature change of 2ºC (21ºC-19ºC) was predicted to occur in the area below the dam. During low flow years, as measured in July, this temperature change ranged from 5ºC (21ºC-16ºC) at the dam site to approximately 1.5ºC (21ºC-19.5ºC) 48 km (30 mi) (RK 120) downstream from the dam (USFWS 1982).

Data compiled by Chart (1987) showed that the maximum summer temperatures below the dam declined approximately 2-3ºC in 1985. A period with no diurnal change in temperature occurred as the river reached baseflows in late summer months (July and August) of 1985 (Chart 1987). Kenney Reservoir was apparently large enough to ameliorate effects of the daily thermal fluctuations of inflow. In addition, the winter outflow below the dam was warm enough to create ice-free conditions throughout the winter months of 1984 and 1985 (Chart 1987). During an "average" water year, Chart (1987) estimated that these subtle thermal alterations should persist 10-15 km below TDD with minimal impact to the native fishes. A comparison between pre- and post TDD thermographs at the Watson Station indicate temperature changes caused by TDD are rapidly attenuated.

***Suspended Sediment Load and Sediment Discharge Data***

Limited data were available for sediment discharge from the Yampa River gaging stations, therefore, we used the Jensen gage station on the Green River to estimate Yampa River sediment transport dynamics. The Yampa River is the only significant river between Flaming Gorge and Jensen, UT; hence, the Yampa River is the primary source of suspended sediment at the Jensen station. Jensen averaged 806,866 tons/month (range 52,651-3,231,564 tons/month) from 1974-1984. The maximum daily load recorded was 2.5 million tons and the lowest was 10 tons. The White River at Watson averaged 139,238 tons/month (range 1,160 to 2,182,600 tons) from 1978-1990. Although sediment discharge data were not available for the Duchesne River, Starvation Reservoir reduced sediment input from the Strawberry River (its primary tributary), thereby reducing the Duchesne River sediment discharge.

At the Watson station, daily suspended sediment data were available from October, 1978, through September, 1990. The White River had large fluctuations in sediment load with storm and snowmelt runoff events. Highest suspended sediment values at Watson occurred in May and June when average daily loads were approximately 20,000 tons, and the lowest values occurred in the winter months when average daily loads were less than 500 tons. The maximum daily sediment load recorded at the Watson station was 121,000 tons on Aug. 8, 1987. The minimum daily value was 12 tons on September 7, 1989. Total monthly suspended sediment loads exceeded 3.0 million tons/month at the Ouray station (USGS 0936900).

The average annual sediment load in the White River directly below Taylor Draw Dam was reduced by sediment deposition in Kenney Reservoir. The retention rate of the concentrations of suspended solids at Kenney Reservoir ranged from 65% to 98% when inflow was less than 1,000 cfs. Retention rates decreased to 30-80% when streamflow exceeded 2,500 cfs (Tobin and Hollowed 1990).

Chart (1987) noted clear water conditions persisted 11 km to the confluence of Douglas Creek (RK 157) where turbidity increased. Lack of sediment input in the TDD tailrace may contribute to long-term degradation of channel morphology in that reach (Chart 1987). At the Watson gaging station, total sediment loads prior to TDD were significantly higher than post TDD sediment loads (Figure 11). Lower flows during the post TDD period partially explain
suspended sediment reduction; however, sediment retention at Kenney Reservoir significantly reduced the White River's total suspended sediment, particularly during the spring runoff.

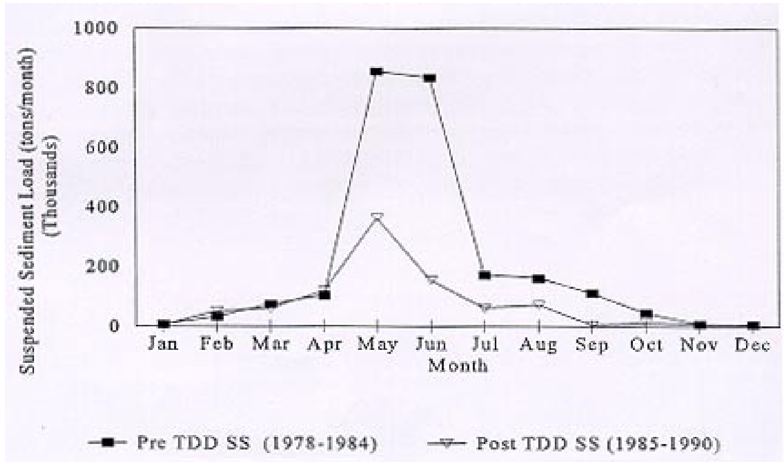



Figure 11. Suspended sediment load at Watson, UT, before and after the installation of Taylor Draw Dam.

### *Specific Conductance*

The specific conductance of the tributaries in the Green River Basin was inversely related to discharge because higher volumes of water dilute the concentration of dissolved solids. The lowest specific conductance occurred during spring when discharge was highest. In the Yampa River, average specific conductance ranged from 190 FS/cm in June to 896 FS/cm in March. The specific conductance of the Green River ranged from 386 FS/cm in June to 841 FS/cm in January. The Duchesne River, however, had a considerably higher specific conductance with values ranging from 1,005 FS/cm in June to 1,771 FS/cm in October.

Specific conductance data for the White River were available from 1965-1972, 1975-1985, and 1987-1991 at the station near Watson. The mean monthly average for the period of record was 764 FS/cm (range 310-1,520 FS/cm). The highest maximum daily value for the period of record was 4,450 FS/cm on August 4, 1975, while the lowest minimum daily value was 136 FS/cm on May 10, 1989. A comparison between past and present specific conductance on the White River suggests little change since 1964 (USGS 0936500), nor has TDD effected the specific conductivity or TDS in the White River.

### *Dissolved Solids*

The volume of dissolved solids (tons/day) varied considerably among the tributaries of the Upper Green River Basin due to differences in discharge among streams. The concentration of dissolved solids (tons/AF), however, were similar between all of the rivers except the Duchesne, which had considerably higher concentrations.

Measurements of the total dissolved solid loads in the White River at the station near Watson averaged 746 tons/day from 1922 to 1984. Highest dissolved solids values occurred in May and June (average for record 1,390 tons/day and 1,290 tons/day, respectively) and lowest values occurred in December and January (average for record 526 tons/day and 515 tons/day, respectively). Total annual loads of dissolved solids for the period of record averaged 272,000 tons/year at the station near Watson and 184,000 tons/year at the station below Meeker (Boyle et al. 1984). Concentration of dissolved solids generally increased from the upper river reaches (RK 354) to the confluence (RK 0).

### *Hardness*

The hardness of water is a measure of the amount of specific ions, both cations and anions, dissolved in a given body of water. Water is considered soft when concentrations of $CaCO_3$ are less than 60 mg/l, moderately hard when concentrations of $CaCO_3$ range between 61 and 121 mg/l, hard when concentrations of $CaCO_3$ exceed 121 mg/l, and very hard when concentrations of $CaCO_3$ exceed 180 mg/l (Tobin and Hollowed 1990). The water hardness of both the Yampa and Green rivers varied between moderately hard and very hard water. The Duchesne River generally was very hard.

The hardness of water in the White River ranged from hard to very hard calcium bicarbonate when streamflow in the White River exceeded 3,500 cfs. When flows were less than 400 cfs, the water quality changed to very hard calcium magnesium sulfate bicarbonate (Tobin and Hollowed 1990). The primary cations in the White River were calcium ($Ca^+$), sodium ($Na^+$), magnesium ($Mg^{2+}$), and potassium ($K^+$). The dominant anions were bicarbonate ($HCO_3^-$), sulfate ($SO_4^{2-}$), and chloride ($Cl^-$) (Boyle et al. 1984).

The concentrations of the major cations and anions generally increased from the headwaters to the confluence of the river. In the upper reaches of the White River, calcium was the major cation followed by magnesium, sodium, and potassium. By contrast, in the lower reaches sodium was the dominant cation followed by calcium and magnesium. The most prominent anion throughout the river was bicarbonate, followed by sulfate and chloride (Boyle 1984). In the lower reaches, sulfate concentrations increased substantially with concentration fluctuations varying with discharge (Melancon 1980).

### *Trace Elements and Heavy Metals*

Trace elements and heavy metals are measured either as concentration in the bedload or as concentration in the river (dissolved plus suspended components). The trace element concentrations of the Green and Yampa rivers were similar, while the Duchesne River generally had higher concentrations (USGS Water Resources Data 1991).

Boyle et al. (1984) evaluated trace element concentrations for arsenic, barium, chromium, copper, iron, manganese, mercury, nickel and zinc. He found that geologic outcrops influenced concentrations of trace elements in the White River. Consequently, trace element concentrations in bed material varied with respect to river kilometer. The concentration of trace elements in bed material were typically less then 100 Fg/l from RK 354 to RK 270. Concentrations of all elements increased sharply downstream of Meeker Dome (RK 270). Concentrations of arsenic, chromium, copper, iron, and manganese continued to rise from RK 270 to RK 227. Levels of barium, mercury, nickel, and zinc fluctuated throughout this same river reach (RK 270-RK 227). Near Rangely, CO (RK 145), concentrations of arsenic, barium, copper, and mercury increased, while concentrations of all other elements decreased slightly. Trace element concentrations in bed material generally stabilized from RK 129 to RK O (Boyle et al. 1984).

The concentration of total recoverable trace element concentrations tended to increase as the river approached the confluence (RK 0). Data for total recoverable trace element concentrations were available for aluminum, copper, iron, lead, manganese, molybdenum, nickel, and zinc. Concentrations of total recoverable lead and zinc demonstrated sharp increases from RK 306 to RK 289. All other recoverable trace elements increased at RK 270 (Meeker Dome). Similarly, concentrations of other trace elements increased from RK 241 (Piceance Creek) to RK 0 (confluence) with the exception of molybdenum (Boyle et al. 1984). No heavy metals or trace elements were detected at dangerous or lethal concentrations in the White River (Boyle et al. 1984).

Tobin and Hollowed (1990) analyzed 22 different trace elements including selenium in Kenney Reservoir and a site just upstream of the reservoir. Selenium concentrations ranged from 2-6 Fg/l. The concentrations of all trace constituents were less than the recommended concentrations established by the State of Colorado for cold water biota.

### *Dissolved Oxygen and pH*

Wind, water turbulence, water current, temperature, and organic matter are all factors that affect levels of dissolved oxygen in a body of water. The Yampa, Green, White, and Duchesne rivers had comparable DO concentrations of approximately 8-9 mg/l (USGS gaging stations). Percent saturation of dissolved oxygen in the White River varied from 98% to 132% at temperatures between 13-22°C (Boyle et al. 1984). Concentration of DO was higher in the winter months (December, January, and February) and lower during the summer months (June, July, and August). Boyle et al. (1984) reported a general reduction in the percent saturation of DO as the White river approached the confluence (RK 0) due to a reduction in the number of rapids. The highest percent saturation of DO (approximately 130%) occurred between RK 243 and RK 228 and the lowest percent saturation (approximately 98%) occurred at RK 265 and at RK 8 (Boyle et al. 1984).

All Green River tributaries were alkaline with pH values averaging 8.0. The White River, like the other tributaries, had pH values generally ranging between 7.5 and 9.0.

## ECOLOGY

Information regarding primary (phytoplankton) production, trophic interaction, invertebrate community and fish community were summarized to provide a description of the biology of the White River system. Data for fish species composition were combined from various studies and reports. Variation in fish sampling gear types, methods and sites precluded extensive catch rate comparisons.

### *Productivity (Including Macroinvertebrates)*

The allochthonous nutrient contribution was composed primarily of detritus. The largest source of coarse particulate organic matter (CPOM) in the White River occurred between RK 150 and RK 80 in an area dominated by cottonwood trees (ERI 1982). The highest concentration of allochthonous input occurred during spring runoff and in the fall, in the form of leaf litter from cottonwood trees (ERI 1982).

The autochthonous nutrient contribution consisted of hydrophytes and algae (periphyton). Periphyton from the taxa Cyanophyta, Chlorophyta, and Chrysophyta were sampled from the White River (ERI 1982; Holden and Selby 1979). The density and distribution of periphyton were spatially and temporally variable in the White River. The highest biomass occurred in the upper reaches of the river and decreased as the river approached the confluence (ERI 1982). The decrease in algal biomass correlated with a decrease in adequate substrate and an increase in turbidity in lower river reaches (ERI 1982). Mean periphyton biomass densities ranged from 50 Fg/m$^2$ to 153 Fg/m$^2$ from RK 197 to RK 181 (Holden and Selby 1979). Periphyton occurred in higher concentrations over substrates larger than 10 cm in diameter (boulders), while lower concentrations were found on substrate ranging between 0.1-0.5 cm in diameter. The highest concentration of periphyton occurred in the summer and fall in less turbid water (ERI 1982).

Overall, the White River had a diverse community of benthic macroinvertebrates (Wullschleger 1990; Ecosystem Research Institute 1982; Carlson et al. 1979; Crosby 1974). Organisms representing over 47 taxa were collected from the river (Wullschleger 1990). In the lower 240 km, total benthic macroinvertebrate biomass, diversity, and density was generally lower than that found above RK 240. Again, community composition parameters were correlated with substrate type and water quality (ERI 1982). Ephemeroptera and Trichoptera dominated the upper reaches (RK 241-RK 213) with clear water and larger substrate (ERI 1983; Carlson et al. 1979; Crosby 1974). Ephemeroptera dominated the reach from RK 213-RK 95.4; Diptera numbers substantially increased from RK 213-RK 151. In the river reach from RK 95.4-RK 34.2, Trichoptera were the dominant invertebrate family. Invertebrates were sparse from RK 34.2 to the confluence (RK 0), but filter feeder biomass was highest in the lower stretches of the river because organic material was more abundant (ERI 1982).

The numbers of invertebrates decreased during and following spring runoff. Holden and Selby (1979) found that the average density of invertebrates was lowest in July but increased rapidly as discharge decreased. Ecosystems Research Institute (1983) reported that the White River invertebrate community after runoff consisted of mayflies, most notably *Traverella* sp. By fall, stoneflies (Plecoptera) comprised a larger portion of the community. Other invertebrates from the order Trichoptera and Chironomidae were present year-round. Species diversity of drifting macroinvertebrates in the White River did not change along the course of the river; however, density and biomass of invertebrates decreased downstream. A comparison between diversity of drift samples and benthic samples suggests that macroinvertebrates drifting from upstream reaches were important components of species composition in the lower reaches of the river (ERI 1982). Wullschleger (1990) found a total of 47 taxa of which 78% were aquatic insects (Ephemeroptera, Trichoptera, Diptera, Odonata, Plecoptera, Hemiptera and Coleoptera) and the remaining 22% were in the non-insect groups (Oligochaeta, Crustacea, Hydroidea and Nematoda) between the stateline (RK 115) and RK 185. More than 95% of the total number comprised nine taxa (6 Ephemeroptera and 3 Trichoptera).

The construction of TDD contributed to increased densities and reduced diversity of invertebrates in the 10 km reach below the dam. Three factors were responsible for this change in the invertebrate community: 1) increased water clarity below TDD which altered the primary productivity and contributed to substrate loss, 2) a decrease in summer temperatures and an increase in winter temperatures due to hypolimnetic releases, and 3) an increase in fish predators from stocking and illicit introduction (Wullschleger 1990). The change in the invertebrate community below TDD included an increase in Oligochaetes and Chironomids with a corresponding decrease in Ephemeroptera (Wullschleger 1990).

### *Fish Community*

Nine native species and 14 nonnative species of fish have been captured in the White River (Table 7). Several researchers reported that native species dominated the fish community in the Colorado section of the White River (RK >115) prior to TDD construction (Chart 1987; ERI 1982; Miller et al. 1982; Carlson et al. 1979; Holden and Selby 1979) (Table 8). The Utah section of the White River (RK 115 to RK 0) historically supported a higher proportion of nonnative fish, with the percentage increasing near the confluence with the Green River (ERI 1982; Miller et al. 1982; Lanigan and Berry 1979; Crosby 1974) (Table 8). Several studies correlated a substantial increase in nonnative fishes in the Colorado section of the White River with completion of TDD in 1984 (Irving and Modde 1994; Martinez et al. 1994; Trammel 1990; Chart 1987) (Figures 12 and 13; Table 8). While the actual numbers of native fishes remained relatively high compared to other sections in the Green River system, the overall native fish

Table 7. Fish species, White River and Kenney Reservoir

| **NATIVE** | **NONNATIVE** | |
|---|---|---|
| Roundtail Chub<br>-*Gila robusta* | Common Carp<br>-*Cyprinus carpio* | Bluegill<br>-*Lepomis macrochirus* |
| Speckled Dace<br>-*Rhinichthys osculus* | Fathead Minnow<br>-*Pimephales promelas* | Green Sunfish<br>-*Lepomis cyanellus* |
| Colorado Pikeminnow<br>-*Ptychocheilus lucius* | Redside Shiner<br>-*Richardsonius* | Smallmouth Bass<br>-*Micropterus dolomieu* |
| Mountain Sucker<br>-*Catostomus platyrhynchus* | Red Shiner<br>-Cyprinella lutrensis | Black Crappie<br>-*Pomoxis* |
| Bluehead Sucker<br>-*Catostomus discobolus* | Brown Trout<br>-*Salmo trutta* | Northern Pike<br>-*Esox lucius* |
| Flannelmouth Sucker<br>-*Catostomus latipinnis* | Rainbow Trout<br>-*Oncorhynchis mykiss* | |
| Flannelmouth Sucker X Bluehead<br>*(hybrid)* | Channel Catfish<br>-*Ictalurus punctatus* | |
| Mountain Whitefish<br>-*Prosopium williamsonii* | Black Bullhead<br>-*Ameiurus melas* | |
| Mottled Sculpin<br>-*Cottus bairdi* | White Sucker<br>-*Catostomus* | |

Table 8. Fish assemblage of the White River, native and nonnative species.

| RK | River Segment | Year | % Native | % Nonnative | Sample Size |
|---|---|---|---|---|---|
| 0-34.2 | 0-50 | 1974-75 | 18.5 | 81.5 | 1218 |
| | 0-50 | 1979 | 29.6 | 70.4 | 9410 |
| | 0-34 | 1981 | 20.9 | 79.1 | 5384 |
| | 0-115 | 1983 | 38.6 | 61.4 | 2023 |
| | 0-50 | 1992 | 53.9 | 46.1 | 141 |
| 34.2-94.5 | 51-90 | 1974-75 | 71.8 | 28.2 | 301 |
| | 51-90 | 1979 | 54.5 | 45.5 | 2280 |
| | 35-95 | 1981 | 40.2 | 59.8 | 5034 |
| 94.5-151 | 91-115 | 1974-75 | 80.3 | 19.7 | 157 |
| | 96-151 | 1981 | 68.8 | 31.2 | 7485 |
| | 91-115 | 1992 | 20.2 | 79.8 | 746 |
| | 115-193 | 1983 | 97.2 | 2.1 | 14558 |
| | 115-193 | 1984 | 81.2 | 18.8 | 50600 |
| | 115-193 | 1985 | 75.2 | 24.8 | 47473 |
| | 115-168 | 1989 | 17.8 | 82.2 | 23433 |
| | 115-168 | 1990 | 23.5 | 76.5 | 40355 |
| | 115-168 | 1992 | 55.8 | 44.2 | 1482 |
| 151-241 | 170-240 | 1975 | 96.6 | 3.4 | 88 |
| | 170-240 | 1976 | 96.6 | 3.4 | 2545 |
| | 170-240 | 1977 | 92.0 | 8.0 | 872 |
| | 170-240 | 1978 | 97.5 | 2.5 | 160 |
| | 200-240 | 1977 | 89.6 | 10.4 | 3067 |
| | 200-240 | 1978 | 89.5 | 10.5 | 1647 |
| | 200-240 | 1979 | 94.0 | 6.0 | 4267 |
| | 168-184 | 1978 | 77.1 | 22.9 | 2383 |
| | 152-240 | 1980 | 77.5 | 22.5 | 5077 |
| | 152-213 | 1981 | 90.2 | 9.8 | 3777 |
| | 214-241 | 1981 | 87.9 | 12.1 | 3732 |

Modified from: Irving and Modde 1994; Trammell 1990; Chart 1987; Radant et al. 1983; Miller et al. 1982; Prewitt et al. 1980; Carlson et al. 1979; Holden and Selby 1979; Lanigan and Berry 1979; Crosby 1974.

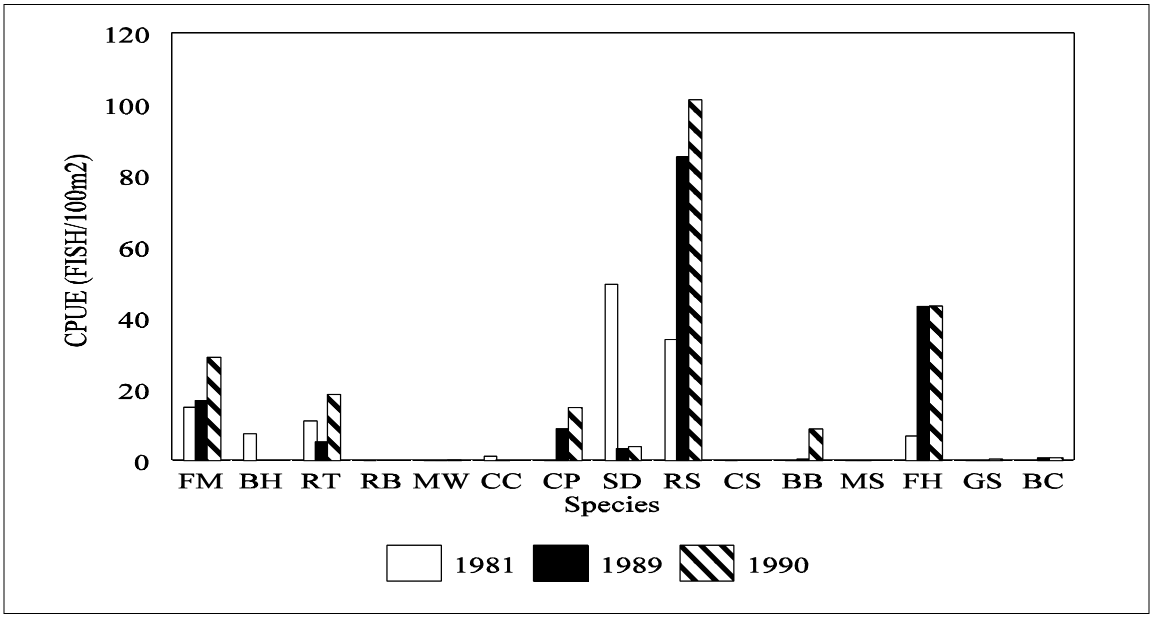



Figure 12. Seining CPUE 1981 (Miller), 1989 (Trammell) and 1990 (Trammell), White River.

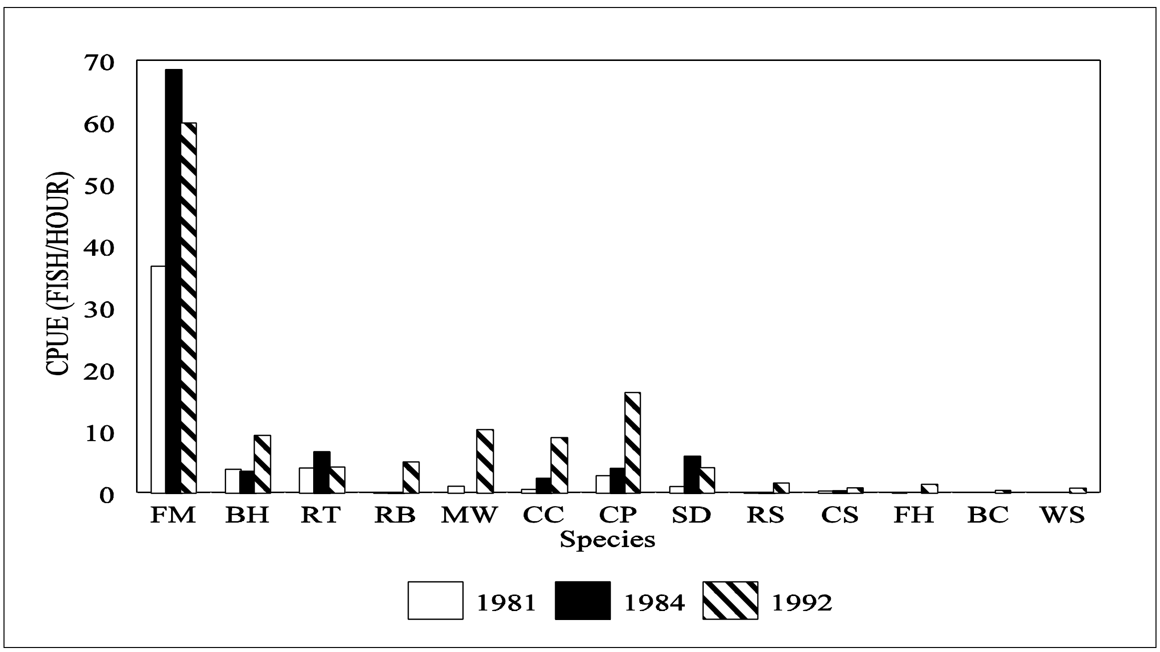



Figure 13. Electrofishing CPUE 1981 (Miller), 1984 (Chart) and 1992 (Trammell), White River.

Key for Figure 12 and 13: FM=Flanelmouth sucker; BH=Bluehead sucker; RT=Rainbow trout; RB=Razorback sucker; MW=Mountain whitefish; CC=Channel catfish; CP=Common Carp; SD=Speckled dace; RS=Red shiner; CS=Colorado pikeminnow; BB=Black bullhead; MS=Mottled sculpin; FH=Fathead minnow; GS=Green sunfish; BC=Black crappie WS=White sucker composition decreased because of the increase in nonnative fish (Martinez et al. 1994; Irving and Modde 1994; Trammell 1990; Chart 1987) (Figures 12 and 13).

The majority of early fish community studies in the White River were conducted in the upper river to assess its potential for sport fishing. Klein (1957) sampled reaches of the White River from above RK 354 (confluence of North and South Forks) to RK 240 (Piceance Creek) to inventory populations of mountain whitefish (*Prosopium williamsonii*). He found mountain whitefish were widely distributed throughout this river reach. Other fish in this area included bluehead sucker (*Catostomus discobolus*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), cutthroat trout (*Oncorhynchis clarki*), flannelmouth sucker (*Catostomus latipinnis*), rainbow trout (*Oncorhynchis mykiss*), and speckled dace (*Rhinichthys osculus*) (Klein 1957). Everhart and May (1973) reported capturing black bullhead (*Ameiurus melas*), brown trout, channel catfish (*Ictalurus punctatus*), Colorado pikeminnow (*Ptychocheilus lucius*), flannelmouth sucker, mottled sculpin (*Cottus bairdi*), mountain sucker (*Catostomus platyrhynchus*), rainbow trout, red shiner (*Cyprinella lutrensis*), and speckled dace from the White River near RK 240 (Piceance Creek).

More recently, fish studies have concentrated on the lower 240 km of the river to evaluate the White River's contribution to recovering the Colorado River Basin endangered fish. A comparison among various studies on the White River yielded results similar to Klein (1957). The most common native fishes captured throughout the river were speckled dace and flannelmouth sucker. Miller et al. (1982) reported that speckled dace were the most abundant native species from RK 241 to RK 34.3, while the flannelmouth sucker was the most abundant species from RK 34.3 to RK 0. Carlson et al. (1979) reported similar results at RK 243 and RK 150 through seining and dipnet sampling; speckled dace dominated (39%) followed by flannelmouth sucker (27%). Crosby (1974) reported a general decrease in total catch of flannelmouth suckers from 48% to 2% from RK 103 to RK 43, respectively. ERI (1982) reported a similar decrease in flannelmouth suckers from 22% to 8% of the total catch from RK 115 (UT/CO border) to RK 0 (confluence with Green River), respectively.

Miller et al. (1982) collected roundtail chubs (*Gila robusta*) and bluehead suckers consistently throughout the river with slightly higher densities of adults and juveniles in the upper sections (RK 240-95). ERI (1982) reported that the percentage of roundtail chubs decreased from 24% to 2% between RK 115 and RK 0.

Red shiners dominated lower reaches of the White River. Crosby (1974) reported a predominance of red shiners from RK 48 to RK 0, where they constituted 78% and 93% of the total catch, respectively. Miller et al. (1982) reported red shiner as the most ubiquitous of the nonnative species throughout the White River. Lanigan and Berry (1979) reported that red shiner comprised 60% of the total fish population near RK 103 (Hell's Hole Canyon) and ERI (1982) reported red shiner as dominating the fish community; constituting 32%, 63%, and 63% of the total catch at RK 115, RK 34, and RK 0, respectively.

Fathead minnow (*Pimephales promelas*), common carp (*Cyprinus carpio*), channel catfish, black crappie (*Pomoxis nigromaculatus*), and rainbow trout were the other nonnative species captured in the White River. Miller et al. (1982) captured carp and fathead minnows in low numbers throughout the river. Carp were the most common species from RK 151.2 to RK 0. ERI (1982) reported that fathead minnows were found in significant numbers only in the upper section of the White River and were seldom abundant in areas with a variety of other fish species.

Following completion of TDD, Chart (1987) reported that early life stages of native fish decreased from 80% (1983 and 1984) to 60% of the total catch below TDD. He attributed this composition change to a proliferation of fathead minnows released from Kenney Reservoir in 1984.

Larval bluehead sucker numbers were considerably lower following completion of TDD (Chart 1987). Martinez et al. (1994) summarized the shift from native to nonnative species throughout development and completion of TDD. Irving and Modde (1994) reported that native fish dominated community composition in the Colorado sections of the White River, 56% native species in 1992 and 67% in 1993. However, nonnative fish were more abundant in the Utah sections, 75% in 1992 and 55% in 1993.

### *Habitat Selection*

Fish community diversity was positively correlated with habitat diversity in the White River (Chart 1987; Miller et al. 1982). In general, habitat diversity was greatest in the upper reaches of the river (RK 215-95); these reaches also had the greatest species diversity. Miller et al. (1982) reported catching the highest number of fish species (13 and 12 species) from RK 241.4 to RK 213.2 and from RK 151.2 to RK 95.4, respectively. The lowest species diversity (9 species) was in the reach from RK 213.2 to 151.2. Backwater habitat contained highest fish densities, particularly smaller minnow species. Eddy habitat frequently yielded the greatest number of larger adult species, and occasionally large numbers of young red shiners, channel catfish, common carp, and roundtail chub.

A large portion of adult bluehead and flannelmouth suckers were captured in run habitat, as well as eddies. Speckled dace and bluehead suckers were associated with riffle habitats consisting of rubble and gravel (Miller et al. 1982). Side channels in the White River did not yield large numbers of any species; red shiner and speckled dace were most common in these areas (Miller et al. 1982). Shoreline habitat yielded high numbers of red shiners and some other larger species such as adult Colorado pikeminnow.

### *Food Habits*

A comprehensive trophic analysis was done by Ecosystem Research Institute in 1981. A comparison among diet richness (number of species) of White River fishes showed a measurable diet shift among species and reaches (ERI 1982). Native fish, led by speckled dace, had higher species richness in their diet than nonnatives. Nonnative species had greater diet richness in the lower river strata (ERI 1982). Ephemeroptera and Diptera were the most common Macroinvertebrates; periphyton comprised 10%-20% of the total diet volume (ERI 1982). Drifting insects became more important in fish diets than benthic organisms in downstream reaches of the White River (ERI 1982).

### *Kenney Reservoir*

Within Kenney Reservoir, a total of 210 phytoplankton species from 7 phyla were identified (Tobin and Hollowed 1990). Diatoms, green algae, and blue-green algae were the most common phytoplankton.

The fish community in Kenney Reservoir was dominated by stocked or illicitly introduced nonnatives such as rainbow trout, fathead minnow, red shiner, channel catfish and black crappie. Flannelmouth suckers and roundtail chubs were the native species most often captured in the reservoir (Trammell 1990).

## ENDANGERED FISH USE

Colorado pikeminnow (*Ptychocheilus lucius*) is the only endangered fish of the four listed species in the UCRB that has been consistently captured in the White River. Lanigan and Berry (1981; 1979) reported catching a bonytail (*Gila elegans*) x humpback chub (*Gila cypha*) hybrid in the lower White River which they photographed but did not preserve. Miller et al. (1982) captured one *Gila* species suspected to be a humpback chub, however it was not preserved for positive identification. Miller et al. (1982) suggested that habitat in the White River is not suitable for either of the endangered *Gila* species. There are no records of razorback sucker (*Xyrauchen texanus*) captures, which may simply be a function of inadequate sampling efforts. Razorback suckers have been documented in the lower section of the Duchesne River. The lower reach of the White River has similar habitat to the Duchesne River; thus, razorback sucker may use this area on a seasonal basis. Additional sampling efforts may be required to determine whether or not razorback sucker inhabit the White River on a seasonal basis. At this time, confirmed information on endangered fish use of the White River is limited to Colorado pikeminnow.

### *Distribution and Abundance*

Colorado pikeminnow use of the White River was first noted by anglers in the 1940's (Seethaler 1978). The first scientific documentation of their occurrence in the river was between 1968 and 1970 in the vicinity of Piceance Creek (RK 240) (Everhart and May 1973). Approximately a dozen fish between 100 and 400 mm and weighing up to 0.7 kg were reported from this area (Seethaler 1978). Since that time, several researchers have caught pikeminnow regularly between Piceance Creek and the confluence with the Green River (Elmblad 1999; Irving and Modde 1994; McAda et al. 1994; Trammel 1990; Chart 1987; Martinez 1986; Radant et al. 1983; ERI 1982; Miller et al. 1982; Carlson et al. 1979; Lanigan and Berry 1979). However, larval and young-of-year (YOY) fish were absent from these collections. In total, over 300 pikeminnow were caught in the White River between 1970 and 1999. The average length of

the fish caught between 1970 and 1994 has been 532 mm TL (range 140-810 mm) (Figure 14). Individuals representing the adult and juvenile life stages were captured. Sixty-eight percent of the fish were adults (over 500 mm TL) (Seethaler 1978). Most of the pikeminnow were captured between RK 170-150 (below TDD) and between RK 50-0 (near the confluence). Following completion of TDD, Martinez (1986) reported only 13% of the pikeminnow captured between the state line and Piceance Creek were above Taylor Draw Dam (RK 240-RK 176), the remaining 87% were captured between the dam site and the CO/UT state line (RK 168-RK 115). Of these fish, 80% were found in the first 16 km (10 mi) below the dam (RK 168-RK 152). Irving and Modde (1994) captured 54 Colorado pikeminnow in the White River, with 43 captures (80%) in the 16 km immediately below TDD; no fish were captured above TDD. Mark-recapture estimates in the 0.4 km below TDD estimate densities of 65 Colorado pikeminnow/km, one of the highest densities in the UCRB (Irving and Modde 1994). Colorado

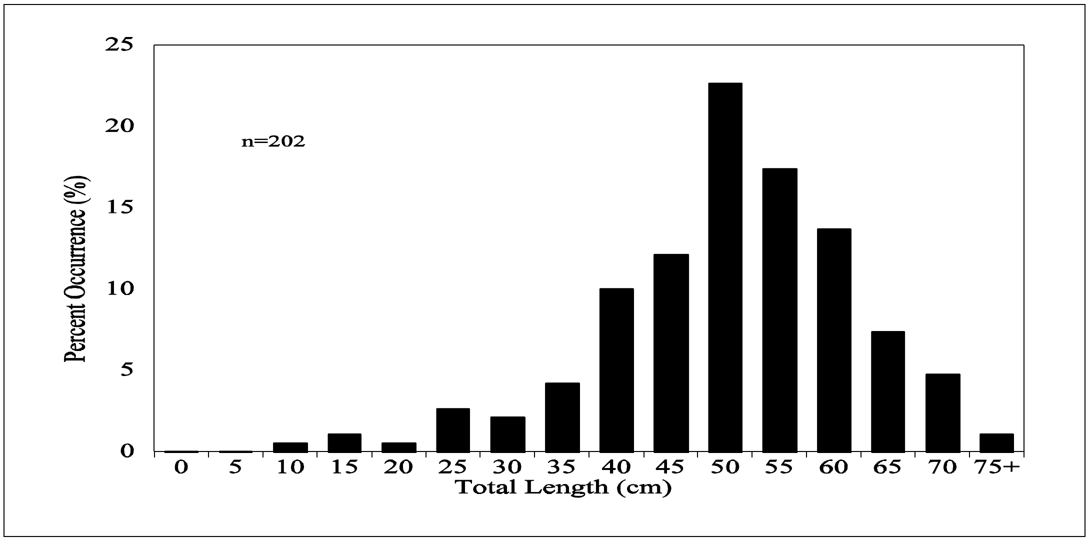



Figure 14. Length frequency of Colorado pikeminnow captured in the White River, 1973-1992.

pikeminnow are now considered extirpated from reaches above the dam, due to TDD acting as a barrier to upstream migration (Martinez et al. 1994). The Colorado Division of Wildlife found total lengths were generally increasing, as was catch per effort, in annual sampling conducted between 1992 and 1999 below TDD (Elmblad 1999; Table 9).

Table 9. Colorado pikeminnow sampling results for repeated transects below Taylor Draw Dam on the White River in Colorado. From Elmblad (1999).

| Year | Captured | CE/mi | Total Length Range (mm) |
|---|---|---|---|
| 1992 | 11 | 1.5 | 584-635 |
| 1993 | 7 | .86 | 441-784 |
| 1994 | 13 | 2.04 | 468-680 |
| 1995 | 15 | 2.04 | 488-757 |
| 1996 | 13 | 1.72 | 552-774 |
| 1997 | 27 | 3.55 | 446-777 |
| 1998 | 18 | 2.47 | 506-754 |
| 1999 | 38 | 4.95 | 455-733 |

CE/mi = total fish captured and observed/9.3 total miles sampled

### *Habitat*

Colorado pikeminnow occupied a variety of habitats throughout the White River including eddies, backwaters, main channel runs, side channels, pools, shorelines, and riffles. Miller et al. (1982) observed an ontogenetic habitat shift, with smaller, younger fish preferring shallow, lower velocity waters and adults preferring open water areas. Adult Colorado pikeminnow were collected by Miller et al. (1982) from eddies (40%), shoreline areas (28%), and main run channels (20%). The predominant substrate was sand (55%), followed by silt (22.5%), and rubble (20%). No adult Colorado pikeminnow were found in backwater areas. Juvenile pikeminnow (116-172 mm) were collected primarily from eddies (35%) and backwaters (29%). Irving and Modde (1994) reported slightly different findings, with the majority of pikeminnow sampled from main channel run habitat throughout the year (fall, winter, spring, and summer). Occasionally, Colorado pikeminnow were associated with cover along cut banks over gravel substrate (Irving and Modde 1994). Colorado pikeminnow were caught in depths averaging 0.7 m and water velocities averaging 0.5 m/s in the White River (Miller et al. 1982). Water temperatures at times of captures ranged from 7-18ºC in the fall, 12-14ºC in spring, and 15-28ºC in summer (Irving and Modde 1994).

Irving and Modde (1994) reported sampling an unusually high percentage (80%) of Colorado pikeminnow directly below Taylor Draw Dam. Elmblad has confirmed this observation (Elmblad 2000, personal communication). They hypothesized that the large plunge pool habitat at the base of the dam, provides large numbers of forage fish being washed over the spillway into the clear, oxygenated water. They further hypothesized that the deep run habitat in main and overflow channels below the dam provided preferred holding, feeding, and over-winter habitat for the adult fish. Concentrations of Colorado pikeminnow and channel catfish below the dam continued to be observed following the installation of the hydroelectric plant (Elmblad 2000, personal communication)

### *Spawning*

The Colorado pikeminnow spawns in deep pool/riffle habitats with cobble/rubble substrates and suitable temperature and flow regimes (Miller et al. 1982). Spawning sites for Colorado pikeminnow have not been documented in the White River; however, Miller et al. (1982) suggest that spawning sites may exist in the lower 81 km (RK 81-RK 0). They observed presumed spawning behavior from a pikeminnow in 1980 ascending the White River to RK 56. Later inspection of the area showed that it was similar to spawning sites on the Yampa. However, substrate type differed between the two areas. Substrate type at the spawning sites in the Yampa was primarily cobble with minimal sand and silt allowing well-washed interstitial voids to form. In contrast, substrate at the suspected spawning sites on the White River was heavily armored with sand and silt, preventing interstitial voids from forming (ERI 1982). In summary, no spawning activity can be confirmed on the White River; however, further investigation of the potential for spawning is certainly warranted.

### *Movement and Migration*

Several researchers have radiotagged Colorado pikeminnow to monitor their seasonal and annual movement (Irving and Modde 1994; Martinez 1986; Tyus and McAda 1984; Radant et al. 1983; Miller et al. 1982). Juvenile Colorado pikeminnow movements are usually concentrated in localized areas. Adults, however, have been documented to undertake spawning migrations of hundreds of kilometers (Tyus and McAda 1984). Martinez (1986) followed an individual pikeminnow for three years, during which time it traveled 700 km (450 mi) moving out of the White River, into the Green, and into the Yampa River to spawn, before returning to the White River. Irving and Modde (1994) radio-tagged 12 adult Colorado pikeminnow, all of which demonstrated long range spawning movements. These pikeminnow initiated their migrations approximately 32 days after the beginning of spring runoff (c. May 14, 1993) and migrated an average of 644 km over a 97 day period between May and October 1993. Seven of these fish apparently used spawning areas in the upper Green and Yampa Rivers, while the other five migrated downstream to the Desolation Canyon area of the Green River. All of these fish returned to the White River after spawning. Other researchers have demonstrated this type of behavior for Colorado pikeminnow in the UCRB (Tyus 1985, Tyus and Karp 1989).

## DISCUSSION

The White River is important to recovery of endangered Colorado pikeminnow in the Upper Colorado River Basin (UCRB). This importance is based on two primary contributions that the river makes to meet the ecological requirements of the species: 1) it provides quality in-channel habitat features that are used by Colorado pikeminnow; and, 2) as one of the least altered major tributaries to the Green River, it makes biological, physical, and chemical contributions to the Green that are similar to its historic contributions. Enhancement of Green River habitats improves conditions for all of the native fish community members, including the other endangered fish species of the system (bonytail, humpback chub, and razorback sucker).

The White River provides 168 RK of quality in-channel habitat that is utilized by adult and juvenile Colorado pikeminnow (Martinez et al. 1994). In addition, the White River provides a migration corridor for adult Colorado pikeminnow during spawning migrations that utilize the Green and Yampa Rivers (Irving and Modde 1994; Martinez et al. 1994). Colorado pikeminnow that utilize the White River may represent one of the few remaining local populations that stabilizes a larger regional population, and therefore the White River system contributions may be critical to Colorado pikeminnow recovery. Understanding the interrelationships between the chemical, physical, and biological elements of this system describes the details of the important contributions the White River can make to endangered fish recovery. It is also important to understand how human activities have altered these relationships so that appropriate recovery actions may be taken as needed.

The hydrological factors contributing to the widespread use of the White River by Colorado pikeminnow include: relatively stable year-round flows compared to other Green River tributaries; 168 RK of relatively unaltered river; and unique seasonal contributions (physical and biological) to the Green River ecosystem. The White River provides more consistent year round flows then either the Yampa or Duchesne Rivers. It has higher baseflows and less seasonal variation then either the Yampa or Duchesne River (Figure 3 and 4). Taylor Draw Dam does not drastically alter the downstream flow or temperature regimes, though it reduces some spring flows and lowers temperatures immediately below the reservoir allowing Colorado pikeminnow to inhabit all 168 RK below TDD. In addition to flows, the White River contributes seasonal biological contributions such as suspended sediment, nutrients and dissolved solids to the Green River. Since impoundment of the Green River at Flaming Gorge in 1964 reduced upstream contributions, the White River's flow contribution to the Green River has increased by 3% compared to pre-development flows. Therefore, the White River now contributes a larger percentage of the total flow to the Green River system than it did historically. These functional contributions from the White River promote persistence and the overall stability of UCRB species and habitats.

According to metapopulation models, the persistence of a regional population depends on the temporal and spatial dynamics of locally adapted subpopulations (e.g., Gilpin and Hanski 1991; Wilcox and Murphy 1984). Isolation, fragmentation, and/or extirpation of locally adapted subpopulations increases risk of regional population extinction through loss of genetic heterogeneity (Leary et al. 1991; Simberloff and Abele 1976), increased vulnerability to environmental and demographic stochasticity (Roff 1974; Wilcox and Murphy 1984) and/or disturbance of deterministic variables that dictate population stability. Occasionally, a subpopulation can be extirpated from a patch, only to be recolonized at a later date (Meffe and Carroll 1994). In a stable metapopulation, local extirpation and recolonization processes can occur over time without jeopardizing the regional population.

Habitat use patterns by Colorado pikeminnow in the White, Yampa, Duchesne, Price, San Rafael, and Green Rivers suggest that the population structure of this fish in the Green River system is characteristic of a metapopulation (Cavalli 1998; Cranney 1994; Irving and Modde 1994; Martinez 1986; Tyus and McAda 1984; Radant et al. 1983; Miller et al. 1982). That is, this population consists of spatially discrete, localized concentrations of fish that are regionally contained (Hanski and Gilpin 1991). A metapopulation describes a collection of subpopulations of a species, each occupying a suitable patch of habitat. These subpopulations are linked together by the emigration and immigration of individuals between patches. Multiple subpopulations of a species, in the presence of suitable habitats, linked by viable migration corridors, increases the stability of that species. The current White River provides habitat and a migration corridor for a Colorado pikeminnow subpopulation, contributing to persistence of the species.

Unobstructed tributaries within the Green River system are important as migratory corridors wherein locally adapted subpopulations add to the stability of the Colorado pikeminnow metapopulation. Although seventy-five kilometers of historical Colorado pikeminnow habitat on the White River are now inaccessible due to obstruction of upstream movement by TDD, the remaining section from TDD to the Green River consistently yields adult Colorado pikeminnow, often at high densities (Elmblad 1999; Irving and Modde 1994; Martinez et al. 1994). Extirpation of Colorado pikeminnow in the White River and other tributaries may seriously jeopardize the continued existence of the UCRB Colorado pikeminnow population. The presence of a healthy Colorado pikeminnow subpopulation in a relatively less disturbed portion of the Green River system strongly suggests that recovery of the Colorado pikeminnow does not depend solely on protection of existing individuals or subpopulations; rather, their recovery will also require spatial and temporal preservation of the natural physical, chemical, and biological integrity of the Green River ecosystem.

The White River was free flowing (with diversions) until completion of Taylor Draw Dam in October, 1984. Taylor Draw Dam is operated so that outflow equals inflow into Kenney Reservoir (USACE 1982). The hydroelectric plant operations have been permitted under the condition that impacts on the downstream river ecosystem are minimized (Colorado River Water Conservation District and Water Users Association #1 1987). The hydroelectric generator at Taylor Draw Dam has experienced some flow fluctuations, particularly during its initial start-up, which may have affected fish below the dam causing them to abandon the area and move downstream (Irving and Modde 1994). Such fluctuating flow events could be detrimental to Colorado pikeminnow population in the White River.

White River hydrology is characterized by stable flows with spring runoff and intermittent storm spikes from July to March. During the spring, streamflow increases as the snow melts starting in April and continuing through June. Maximum streamflow occurs from late May to early June. Spatial and temporal variability in the historic flow regime, including periods of low flow (drought conditions) and extremely high flows (spring runoff and large storm events), are an important component of the river ecology (Martinez 1986). Although total discharge of the White River has not been significantly changed, irrigation diversions and TDD have altered the temporal flow regime of the White River. Changes in the temporal flow regime from the early period (1923-1946) to the post TDD period (1985-1999) include slightly reduced spring floods, higher baseflows and distinctly lower summer flows.

Changes in flow regime may adversely affect physical and chemical parameters such as suspended sediment load, channel morphology, and habitat availability (Stanford 1993; Chart 1987). Few of the White River investigations reviewed quantified habitat availability and channel morphology; consequently, a temporal assessment of geomorphic change of the White River is difficult. Geomorphic channel changes often take years to adjust to altered flow regimes. Future geomorphic analysis of the White River channel geomorphology would be valuable for evaluating and monitoring effects of altered hydrology on the physical river environment.

Hypolimnetic reservoir releases from Taylor Draw Dam have stabilized seasonal and diurnal temperature fluctuations (Chart 1987). Kaeding and Osmundson (1988) hypothesized that cooler water temperatures decrease growth rates of adult and juvenile pikeminnow and delay annual spawning cycles. Diurnal thermal constancy below TDD has not been shown to negatively affect resident Colorado pikeminnow populations because relatively high numbers of Colorado pikeminnow of gradually increasing total lengths (Elmblad 1999) have been sampled throughout the post TDD period. Spawning in the White River by Colorado pikeminnow has not been documented, which may or may not have been affected by cooler temperatures. The possibility that the Colorado pikeminnow and other native fauna are subtly being affected should not be overlooked, because these organisms have evolved life history adaptations, such as temperature cues for spawning, that are specific to the variable environmental conditions (Ward 1984; Ward and Stanford 1979). During winter months, higher water temperatures below the dam prevent ice formation for 10 to 15 km downstream. De-icing may change overwinter habitat conditions and disrupt seasonal cues, consequently affecting survival of the Colorado pikeminnow ( Valdez 1995; Irving and Modde 1994; Chart 1987).

The Taylor Draw Dam Environmental Assessment reported substantial changes in suspended sediment load of the White River below TDD. Tobin and Hallowed (1990) estimated sediment retention rates of 30% to 98% in Kenney Reservoir for different streamflows. Both Chart (1987) and Wullschleger (1990) noted a reduction in turbidity below TDD. Chart and Bergersen (1992) reported that some native fish species, most notably the flannelmouth sucker, vacated the tailrace area because of lowered turbidities and temperatures. Because turbidity is an important environmental parameter affecting primary production, water temperature and, in turn, diets and behavior of invertebrates and fishes (Chart 1987; Wullschleger 1990), White River suspended sediment levels should be monitored in future research efforts.

Investigators have noted that a more stable thermal regime, increased water clarity, and substrate armoring below TDD provide a favorable environment for algae growth (Chart 1987; Martinez 1986). Subsequently, a greater food base and habitat heterogeneity are available for invertebrate and fish communities (Chart 1987). Wullschleger (1990) found that macroinvertebrate density increased, but their diversity decreased in the tailrace of TDD in the White River.

Water chemistry analyses showed that TDD does not significantly change DO levels, pH levels or concentrations of trace elements in the White River. Selenium levels in the White River and Kenney Reservoir ranged from 2 to 6 Fg/l, well below the toxic threshold for cold water biota (Tobin and Hollowed 1990). However, irrigation return flow, effluent from urban communities and oil development are all potential toxin sources for Kenney Reservoir and the White River which could be passed on to the biota if sediments were resuspended. These sources should be monitored so that preventative or remedial actions can be taken if needed.

Prior to the completion of the dam, Carlson et al. (1979) and Martinez (1986) documented the presence of Colorado pikeminnow from Piceance Creek (RK 240) to the confluence with the Green River (RK 0). Although White River water chemistry did not substantially change as a result of Taylor Draw Dam, it has eliminated over 70 km or approximately 29% of Colorado pikeminnow habitat and migratory corridors (Martinez 1986).

Recent shifts in the fish of the White River community occurred (Elmblad 1999; Martinez et al. 1994). Historically, the upper reaches of the White River supported a predominately native fish community including Colorado pikeminnow. Impoundment of the river fragmented the river corridor, facilitated propagation of nonnative fish populations, and altered downstream habitat conditions (Chart 1987; Irving and Modde 1994; Martinez et al. 1994; Trammell 1990), indirectly affecting fish community structure. Stocked rainbow trout and fathead minnows were the first nonnative fishes to exploit the altered White River system (Chart 1987). Black crappie and red shiners also proliferated in the lentic reservoir environment and subsequently spread throughout the river downstream of the dam. Fluctuating proportions of native vs. nonnative fish (Elmblad 1999) indicates continued community sampling is indicated to monitor for changes.

## RECOMMENDATIONS

The following management objectives and recommendations are based on information assimilated in this report and on guidelines proposed by Stanford (1993). These objectives are designed to develop an effective management plan for the White River to protect and recover the Colorado pikeminnow. Many of these recommendations are applicable to other tributaries in the UCRB.

***1. Recognize the White River's contribution and significance to the Upper Colorado River Basin ecosystem***

The White River enhances the stability of Colorado pikeminnow population in the UCRB. The recovery programs should recognize that the Colorado pikeminnow using the White River are part of a larger regional population (metapopulation). Actions taken to enhance recovery of this species, therefore, must take into account how the actions effect stability of the entire regional population, not just those fish that occupy the White River.

A comparison of the early development period to the post Taylor Draw Dam period indicates that White River streamflow contribution to the Green River is currently a greater proportion of total discharge than historically. Because hydrologic data describing the river completely free of diversions is not available, this difference is probably greater than the available data indicate. Most of this difference occurs during spring runoff. This change is mainly due to a decrease in discharge from Flaming Gorge during spring runoff; consequently, the White River may play a greater role in the ecology of the Green River now than it did historically.

The White River provides more consistent year round flows to the Green River than other Green River tributaries (Duchesne and Yampa Rivers). The more consistent year round flows from the White River may be critical during non-spawning periods for resident Colorado pikeminnow in the White River. However, the seasonality of flows, particularly spring floods, are also important to native fish species. Flood events position and clear spawning substrates, and may provide spawning cues. Therefore they are a desirable hydrograph feature. Maintaining seasonally variable flows with natural daily fluctuations similar to the historic hydrograph is imperative for insuring the quality habitat and flow patterns needed for the White River Colorado pikeminnow population.

An immediate concern in the White River and Green River ecosystems is invasion of nonnative fishes. Impoundment of the White River has allowed nonnatives to proliferate there (Martinez et al. 1994). Emigration of these nonnative species into the Green River has been deleterious to the native fish in this quality nursery habitat section of the Green River. Efforts to prevent emigration of nonnative species into the Green River must continue. The Colorado Division of Wildlife currently stocks only rainbow trout and one time fertile channel catfish. Trout are considered relatively innocuous to the native species and catfish are not able to reproduce due to cold water temperatures (Martinez et al. 1994).

***2. Closely monitor physical, hydrological and biological components of the White River***

An understanding of the White River ecosystem requires continuous monitoring of discharge, suspended sediment, temperature, and water chemistry. To facilitate monitoring the physical and hydrological components and trends, installing a gaging station below the dam should be evaluated and data collection at other gage stations should continue. Continuation of ISMP sampling below TDD and near the confluence with the Green River will facilitate monitoring trends in the fish community, most importantly the Colorado pikeminnow. To enhance the biological database, an interagency team should do more extensive sampling along the White River every 5 years. This team would assess hydrological, physical, and biological variables from each of the five reaches outlined in Table 10. This sampling should include: characterization of the fish community, including small-bodied fish; reevaluation of potential spawning sites in the lower 80 kilometers; potential toxin deposition monitoring the macroinvertebrate community; monitoring suspended sediment; and monitoring channel geomorphology.

While many potential questions exist which might be asked regarding native fish species use of the White River, a few are prominent and relevant to recovery efforts:

a) Though potential habitat appears extant, use of the lower 50 km of the White River by razorback suckers has not been documented. Additional surveys should be conducted to look for adults of this species and to more explicitly delineate where they may occur.
b) More intensive examinations of the lowest three reaches of the river should also help characterize the fish community found there, potentially including bonytail and humpback chub, as suggested by earlier studies.
c) Current monitoring and sampling efforts emphasize adult monitoring. Additional studies should also search for YOY and juvenile fish. If the White River pikeminnow are part of a regional metapopulation, as previous work suggests, at what age do they enter the White River and where do they come from? If occasional "flushing", or flood, flows can be released from TDD (to move cobble and clean interstitial spaces), monitoring for drifting Colorado pikeminnow larvae would be valuable.

d) If Colorado pikeminnow were to spawn in the White River, it is likely the larvae would be heavily preyed upon by the nonnative fish species which are present. Nonnative control actions in the river should be implemented.

e) To document the condition and relative proportion of native fish in the White River, as well as documenting the same parameters for nonnatives, regular community sampling should be initiated at established transects. By using the same protocols at the same locations for years, important trends can be documented, providing fundamental information on which important management decisions can be based.

Table 10. Recommended 5 year monitoring sections on the White River.

| Reach | River kilometer | Location | Physical characteristics |
|---|---|---|---|
| | | | |
| 1 | 0 - 34 | confluence with the Green River to Mountain Fuel Bridge | Wide, low gradient alluvial plain. |
| 2 | 34 - 95.4 | Mountain Fuel Bridge to Ignacio Bridge | Meandering channel in low canyons. |
| 3 | 95.4 - 150 | Ignacio Bridge to Douglas Creek | Steep, higher gradient canyon section. |
| 4 | 150 - 168 | Douglas Creek to Taylor Draw Dam | Impacted by Taylor Draw Dam. |
| 5 | 169 - 241 | Kenney Reservoir to Piceance Creek | Historic Colorado pikeminnow habitat. Dam blocks upstream migration to this historic range. |

***3. Implement discharges with seasonality***

Natural spatial and temporal flow variation is needed to maintain biotic and abiotic resources within a river ecosystem. Hill and Platts (1991) identified four flow regimes necessary to maintain ecosystem integrity: instream flows, channel maintenance flows, riparian maintenance flows, and valley maintenance flows. Instream flows are necessary to meet life history requirements of fishes. Channel maintenance flows maintain instream habitat features and geomorphology along stream banks. Riparian flows maintain active riparian areas, adjacent upland habitats, water tables, and soil saturation zones. Finally, flood flows maintain functioning floodplains and valley features which are frequently integral to the health of the ecosystem (Hill and Platts 1991).

To maintain this variable flow regime, several aspects of hydrology must be recognized.

a) Annual discharge, inclusive of timing and duration, should continue to be governed by seasonality and annual precipitation so that discharge from Taylor Draw Dam equals inflow into Kenney Reservoir.

b) Daily fluctuations below TDD should be limited to 5% , except when greater changes are needed to adjust to inflows to Kenney Reservoir.

c) Future water development projects should be compatible with maintaining seasonal flow requirements.

d) Water conservation should be encouraged.

e) While TDD operates as a run of the river facility which maintains historic mean flows, it has reduced the magnitude of flood events on the White River. Because such floods have the potential to move larger substrate components and clear silt, sand, and other debris from interstitial spaces in cobble beds, thereby increasing Colorado pikeminnow spawning-type habitat, the potential for occasional flood flow (>8,000 cfs as measured at Watson) should be released from TDD whenever the necessary water is made available by runoff and/or storms.

f) To insure and enhance the integrity of the river flows, especially during summer months, water rights should be acquired for the purpose of providing instream flow needs for fish.

Because many interacting variables affect fish populations, no simple method exists for assessing the relationship between abiotic factors such as flow regime and channel morphology and faunal communities (Kaeding and Osmundson 1989). Stanford (1993) proposed using a "trial and error" system to determine streamflows. By monitoring response of a given parameter, such as channel morphology, or fish population response to variable discharges, some general relationships affecting endangered fish can be elicited. These observations can be utilized to more specifically quantify flows needed to support the native fish community within a program of adaptive management.

### *4. Adaptive Management*

Because many uncertainties remain regarding the relationship between populations of endangered fish of the Upper Colorado River Basin and discharge, flow seasonalities may not be the only variable limiting native fishes. Interspecific competition and predation by nonnatives may hinder recovery of the Colorado pikeminnow regardless of discharge (Stanford 1993). Any future plan for management of the White River should allow for interactive management plans to be developed as new information about endangered fish is acquired.

## BIBLIOGRAPHY


Behnke, R. J., and D. W. Benson. 1983. Endangered and threatened fishes of the Upper Colorado River Basin. Cooperative Extension Service Bulletin 503A. Colorado State University, Fort Collins, Colorado.

Boyle, J. M., K. J. Covay, and D. P. Bauer. 1984. Quantity and quality of streamflow in the White River basin. Water Resources Investigations Report 84-4022. U.S. Geological Survey, Lakewood, Colorado. 84 pp.

Carlson, C. A., and R. T. Muth. 1993. Endangered species management. Pages 355-381 in C. C. Kohler and W. A. Hubert, editors. Inland Fisheries Management in North America. American Fisheries Society, Bethesda, Maryland.

Carlson, C. A., C. G. Prewitt, D. E. Snyder, E. J. Wick, E. L. Ames, and W. D. Fronk. 1979. Fishes and Macroinvertebrates of the White and Yampa Rivers, Colorado. Final Baseline Report. U.S. Bureau of Land Management, Colorado State University, Ft. Collins, Colorado. 159 pp.

Cavalli, P. 1998. Fish community investigations in the lower Price River, 1996-1997. Draft Final Report. Utah Division of Wildlife Resources.

Chart, T. E. 1987. The initial effect of impoundment on the fish community of the White River, Colorado. Master's thesis. Colorado State University, Ft. Collins, Colorado.

Chart, T. E., and E. P. Bergersen. 1992. Impact of mainstream impoundment on the distribution and movements of the resident flannelmouth sucker (*Catostomus latipinnis*) population in the White River, Colorado. The Southwestern Naturalist 37(1):9-15.

Colorado Division of Water Resources. 1992-1994. Annual Water Diversion Reports, White River. Office of the State Engineer, Ed Blank. Steamboat Springs, Colorado.

Colorado Division of Water Resources. 1992-1994. Annual Evaporation Depletions on Kenney Reservoir, White River. Office of the State Engineer, Ed Blank. Steamboat Springs, Colorado.

Colorado River Water Conservation District and Water Users' Association No. 1 in the Colorado River Water Conservation District. 1987. Safety and design assessment for the Taylor Draw Hydroelectric Station Project, FERC No. 8914-000, Colorado. Filed July 6, 1987.

Connell, J. H., and W. P. Sousa. 1983. On the evidence needed to judge ecological stability of persistence. American Naturalist 121(6):789-824.

Cranney, J. S. 1994. Lower Duschesne river fishery investigation - 1993. Draft Report. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Crosby, C. 1974. White River report. Utah Division of Wildlife Resources. Salt Lake City, Utah. 36 pp.

Ecosystem Research Institute (ERI). 1982. Impact assessment of the White River Dam. White River Shale Oil Corporation. 94 pp.

Ecosystem Research Institute (ERI). 1983. Draft annual report 1983 aquatic biology monitoring program. White River Shale Oil Corporation. 80 pp.

Elmblad, W.R. 1999. Interagency Standardized Monitoring Program (ESMP) on the CO, White, and Yampa R.S. in CO; FY99 Annual Report for Project 22b. UCRRIP, Denver, Co.

Everhart, W. H., and B. E. May. 1973. Effects of chemical variation in aquatic environment: Volume 1 biota and chemistry of Piceance Creek. EPA-R3-73-011a. U.S. Environmental Protection Agency. 117 pp.

Gilpin, M., and I. Hanski. 1991. Metapopulation Dynamics: Emperical and Theoretical Investigations. Academic Press, San Diego, California.

Hawkins, J. A. 1991. Age and growth of Colorado pikeminnow from the Upper Colorado River basin, 1978-1990. Colorado State University, Fort Collins, Colorado. 64 pp.

Hawkins, J. A., and T. P. Nesler. 1991. Nonnative fishes of the Upper Colorado River Basin: an issue paper. Colorado State University and Colorado Division of Wildlife, Fort Collins, Colorado. 72 pp.

Hill, M. T., and W. S. Platts. 1991. Ecological and geomorphological concepts for instream and out-of-channel flow requirements. Rivers 2(3):198-210.

Holden, P. B., and D. A. Selby. 1979. An aquatic biology survey of the White River (Colorado) to assess potential impact of a proposed water withdrawal system. BIO/WEST Report PR-21-1. Unpublished report submitted to Burns and McDonnell, Kansas City, Missouri. 35 pp.

Irving, D. B., and T. Modde. 1994. Assessment of Colorado pikeminnow in the White River, Colorado and Utah, 1992-1994. Final Report. U.S. Fish & Wildlife Service. 79 pp.

Kaeding, L. R., and D. B. Osmundson. 1988. Interaction of slow growth and increased early-life mortality: a hypothesis on the decline of Colorado pikeminnow in the upstream regions of its historic range. Environmental Biology of Fishes 22(4):287-298.

Kaeding, L. R., and D. B. Osmundson. 1989. Biologically defensible flow recommendations for the maintenance and enhancement of Colorado pikeminnow habitat in the '15-mile' reach of the Upper Colorado River during July, August and September. Final Report. U.S. Fish and Wildlife Service, Grand Junction, Colorado. 169 pp.

Klein, W. D. 1957. A partial census of the whitefish and trout populations in the Yampa and White Rivers and their tributaries. Special Purpose Report 47. Colorado Division of Wildlife, Denver, Colorado. 18 pp.

Lanigan, S. H., and C. R. Berry, Jr. 1979. Distribution and abundance of endemic fishes in the White River in Utah. Final Contract Report. Bureau of Land Management, Salt Lake City, Utah. 84 pp.

Lanigan, S. H., and C. R. Berry, Jr. 1981. Distribution of fishes in the White River, Utah. The Southwestern Naturalist 26:389-393.

Leary, R. F., F. W. Allendorf, and S. H. Forbes. 1991. Conservation genetics of bull trout in the Columbia and Klamath river drainages. Wild Trout and Salmon Genetics Laboratory Report. Division of Biological Sciences, University of Montana, Missoula, Montana. 32 pp.

Martinez, P. J. 1986. White River Taylor Draw Project pre and post impoundment fish community investigations final report. Colorado Division of Wildlife, Grand Junction, Colorado. 121 pp.

Martinez, P. J., T. E. Chart, M. A. Trammell, J. G. Wullschleger, and E. P. Bergersen. 1994. Fish species composition before and after construction of a mainstem reservoir on the White River, Colorado. Environmental Biology of Fishes 40:227-239.

McAda, C. W., B. Bates, S. Cranney, T. Chart, B. Emblad, and T. Nesler. 1994. Interagency Standardized Monitoring Program. Summary of Results, 1986-1992. Draft Final Report. U.S. Fish and Wildlife Service, Utah Division of Wildlife Resources, and Colorado Division of Wildlife.

McAda, C. W., and L. R. Kaeding. 1990. Physical changes in the Gunnison and Colorado rivers resulting from construction of the Aspinall unit and related projects with hypotheses to assess the effects on the endangered fishes. Final Report. U.S. Fish and Wildlife Service.

Meffe, G. K., and C. R. Carroll. 1994. Principles of Conservation. First Edition. Sinauer Associates, Inc. Sunderland, Massachusetts.

Melancon, S. M. 1980. Assessment of energy resource development impact on water quality: the Yampa and White river basins. EPA-600/7-80-151. Environmental Protection Agency. Las Vegas, Nevada. 168 pp.

Miller, W. H., D. L. Archer, H. M. Tyus, and K. C. Harper. 1982. White River fishes study. Final Report. Colorado River Fishery Project, U.S. Fish & Wildlife Service, Salt Lake City, Utah. 58 pp.

Muth, R. T., and T. P. Nesler. 1993. Associations among flow and temperature regimes and spawning periods and abundance of young of selected fishes, lower Yampa River, Colorado, 1980-1984. Final Report. Larval Fish Laboratory, Colorado State University, Ft. Collins, Colorado.

Prewitt, C., D. Langlois, J. Torres, E. Wick, C. Carlson, and D. Snyder. 1980. Colorado squawfish and humpback chub population and habitat monitoring. SE-3-1; Endangered Wildlife Investigations. Colorado Division of Wildlife, Ft. Collins, Colorado. 54 pp.

Radant, R. D., J. S. Cranney, R. G. Ruesink, and K. Rose. 1983. Colorado pikeminnow investigation White River, Utah. Utah Division of Wildlife Resources. Salt Lake City, Utah. 39 pp.

Roff, D. A. 1974. The analysis of a population model demonstrating the importance of dispersal in a heterogeneous environment. Oecologia 15:259-275.

Seethaler, K. 1978. Life history and ecology of the Colorado pikeminnow (*Ptychocheilus lucius*) in the upper Colorado River basin. Master's thesis. Utah State University, Logan, Utah.

Simberloff, D., and L. G. Abele. 1976. Island biogeography theory and conservation practice. Science 191:285-286.

Stanford, J. A. 1993. Instream flows to assist the recovery of endangered fishes in the Upper Colorado River Basin: review and synthesis of ecological information, issues, methods and rationale. Final Report. FLBS Open File Report 130-93. Prepared for the Recovery Implementation Program for Endangered Fish and the U.S. Fish & Wildlife Service.
89 pp.

Tobin, R. L., and C. P. Hollowed. 1990. Water quality and sediment transport characteristics in Kenney Reservoir, White River basin, northwestern Colorado. Water Resources Investigations Report 90-4071. U.S. Geological Survey, Lakewood, Colorado. 218 pp.

Trammell, M. T. 1990. Evaluation of Colorado pikeminnow stocking in Kenney Reservoir, Rangely, Colorado. Master's Thesis. Colorado State University, Ft. Collins, Colorado. 64 pp.

Tyus, H. M. 1985. Homing behavior noted for Colorado pikeminnow. Copeia 1:213-215.

Tyus, H. M., and C. A. Karp. 1989. Habitat use and streamflow needs of rare and endangered fishes, Yampa River, Colorado. Biological Report 89(14). Colorado River Fisheries Project, U. S. Fish and Wildlife Service.

Tyus, H. M., and C. W. McAda. 1984. Migration, movements and habitat preferences of Colorado pikeminnow, *Ptychocheilus lucius*, in the Green, White and Yampa river, Colorado and Utah. The Southwestern Naturalist 29(3):289-299.

U. S. Fish and Wildlife Service. 1982. Biological Opinion-Taylor Draw Reservoir Project, Colorado, to Army Corps of Engineers, May 20.

U. S. Geological Survey. Colorado Water Resources Data. 1910-1994.

U. S. Geological Survey. Utah Water Resources Data. 1910-1994.

Utah Climate Center. 1930-1994. Utah State University, Logan, Utah.

Valdez, R.A. 1995. Synthesis of winter investigation of endangered fish in the Green River below Flaming Gorge Dam. Five year Flaming Gorge research program FY 94. Study #18-11. Bio/West Inc., Logan, UT.

Ward, J. V. 1984. Stream regulation of the Upper Colorado River: channel configuration and thermal heterogeneity. Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie 22:1862-1866.

Ward, J. V., and J. A. Stanford. 1979. The Ecology of Regulated Streams. Plenum Press, New York, New York. 398 pp.

Wilcox, B. A., and D. D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. American Naturalist 125:879-887.

Wullschleger, J. G. 1990. Initial impacts of an impoundment on the downstream benthic invertebrate fauna. Master's Thesis. Colorado State University, Fort Collins, Colorado. 106 pp.